ATTENTIONAL CAPACITY LIMITS IN FACE PROCESSING: INTERFERENCE AND REPETITION PRIMING FROM IRRELEVANT FACES

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1. Preface

The way we experience our environment depends to a large extent on what we attend to. Selective attention describes the mechanisms that enable us to choose to process one stream of information rather than another. A matter of great debate over decades in the field of selective attention is how the ignored information is handled by the perceptual system, and whether this irrelevant information as a consequence is lost for subsequent analysis.

The human face is of outstanding social relevance, and it appears plausible to believe that faces may be treated in a special way by our perceptual system. The idea that faces are "special" objects was inspired by clinical (Bodamer, 1947) and experimental (Yin, 1969) evidence. More recently, brain regions were identified that are activated preferably by faces (e.g., Kanwisher, McDermott, & Chun, 1997). Moreover, some recent research has suggested that faces may have a special capability in attracting attention and in being processed despite massively reduced availability of attentional resources.

Although both face perception and selective attention have long separate research traditions, the interaction of these aspects has only recently started to be examined, and specifically the respective underlying neural mechanisms are far from being entirely understood. Accordingly, this thesis aims to provide evidence for the influence of attention on face perception, and specifically focuses on the neural substrates underlying these processes.

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2. Introduction

2.1. Attention

Attention is a central aspect of cognition due to its role in maintaining a vigilant or alert state, in orienting to sensory events, and in detecting events for focal (conscious) processing (Posner & Petersen, 1990).

In the current thesis, the focus will be on selective attention. The two main questions, and matter of intense controversy in research on selective attention, are i) how relevant information is selected from the stream of irrelevant input, and ii) how irrelevant information is effectively ignored (Desimone & Duncan, 1995; Driver, 2001). This latter aspect is considered an especially important feature of attentional processes, as it protects our capacity-limited processing system from being overloaded. It is beyond the scope of this thesis to provide a comprehensive overview of the vast amount of related studies. Thus, in the next section I will broadly outline the most influential theories of selective attention that are related to the current work.

2.1.1. Filter accounts of selective attention

In an early filter model, Broadbent (1958) proposed that information processing is limited, and attention operates as a filter at early stages of information processing. This account was based on experiments initially carried out in the auditory domain, reporting a breakdown in performance when input came from more than one source at the same time. Specifically, participants were unable to report the verbal content of a message presented to one ear while they simultaneously repeated a second message presented to the other ear (Cherry, 1953). Conflicting with this theory, Moray (1959) found that participants were able to report some highly important signals, such as the participants' own name, when these were presented in the irrelevant message stream ("identification paradox"). Moray suggested that a specific system located before the filter analyses the input and detects highly important information. Alternatively, selection has been suggested to occur at a later stage, after all input has been completely analysed ("late selection account", e.g. Deutsch & Deutsch, 1963) or by assuming attenuation instead of complete filtering or blocking of the input (Treisman, 1960, 1964). According to this latter account, the central filter is only used when two or more competing inputs together overload the central decision channel (Treisman, 1964). Treisman & Gelade (1980) formulated yet another influential account, the Feature Integration Theory (FIT). According to the FIT, different features of visual stimuli are extracted in parallel and "preattentively", that is, without attention involvement. Attention is only needed to integrate the features (i.e., shape, colour, orientation) into an appropriate unified percept of a multidimensional object. This is exemplified in visual search paradigms, in which a unique target object "pops out" in an array of identical distractor objects, such as a vertical line target among horizontal line distractors. This pop out occurs largely irrespective of the number of distractors, suggesting parallel processing of features. Critically, targets defined by conjunctions of features (e.g., a vertical red line in an array of horizontal red and vertical green lines) cannot access this efficient parallel search, suggesting the need for attention to "bind" features together.

2.1.2. A Capacity account: Perceptual Load Theory

As an alternative to filter accounts, Lavie proposed a "capacity-model" of selective attention, the "Perceptual Load Theory" (de Fockert, Rees, Frith, & Lavie, 2001; Lavie, 1995; Lavie & Fox, 2000; Lavie, Hirst, de Fockert, & Viding, 2004; Lavie, Ro, & Russell, 2003; Lavie & Tsal, 1994). A similar approach has already been formulated by Kahneman (Kahneman, 1973; Kahneman & Chajczyk, 1983), who suggested that inconsistent results from studies favouring early vs. late selection might be due to a paradigmatic shift in the field of attention from the use of rather complex tasks, supporting early selection, to rather easy tasks supporting late selection accounts (Kahneman & Treisman, 1984). Lavie and Tsal (1994) argued that this paradigmatic shift included a systematic variation of perceptual load. According to the Perceptual Load Theory, selectivity only occurs for loaded processes. Information will be processed unless a limit of the processing resource is reached. Critically, any spare capacity that is not consumed by the processing of high-prioritised relevant information is *automatically* allocated to irrelevant information. This process is not under the perceiver's voluntary control (i.e., automatic), and the perceiver cannot choose to inhibit the allocation of attention and thus reduce the amount of attention paid.

Lavie (1995) tested this model by investigating distractor interference in a modified Eriksen flanker paradigm (Eriksen & Eriksen, 1974), and applying manipulations of perceptual load, such as varying the relevant display set size of items among which the target appeared. In this paradigm, participants were required to make choice responses to the identity of central target letters. A critical distractor that could be incompatible (i.e., requiring a different response), neutral, or compatible in relation to the target response was located below or above the target letter. Response times to the target as a function of distractor type and perceptual load were analysed, and distractor processing was assumed when performance varied between compatible, incompatible and neutral distractor conditions. In line with the Perceptual Load Theory, distractor interference was found consistently under low, but not under high perceptual load.

In the following, the predictions made by the Perceptual Load Theory were confirmed for a number of different stimulus classes, including moving dot patterns (Rees, Frith, & Lavie, 1997), lexical stimuli (Lavie, 1995), or scenes (Yi, Woodman, Widders, Marois, & Chun, 2004). The Perceptual Load Theory combines elements of early selection accounts (limitations of processing capacity) with elements of late selection accounts (automaticity). By using the term “perceptual” Lavie pointed out that load manipulation applies to early perceptual routines, and not to post-perceptual processes. In fact, manipulation of memory load (as an example for post-perceptual load) has been shown to cause different effects, in that high working memory load either had no effect on distractor processing (Yi et al., 2004) or even increased distractor processing (de Fockert et al., 2001).

As a result, Lavie adapted her model to account for these findings (Lavie et al., 2004). She reasoned that the availability of working memory is crucial for directing attention to relevant vs. irrelevant stimuli in a selective attention task. Thus, high working memory load reduces the participants’ ability to distinguish between targets and distractors, resulting in increased processing of the distractors. Critically, rejecting distractors depends on at least two separable mechanisms, a passive perceptual selection mechanism analogous to the mechanism described in the Perceptual Load account, and an active cognitive control mechanism, which actively minimises intrusion from distractors.

2.2. Attention in Face Perception

As mentioned before, faces may be treated in a special way by our perceptual system. The beginning of this section is dedicated to evidence in favour of perceptual selectivity in face processing. Extending this idea, research supporting attentional selectivity for faces is outlined subsequently in this section, exemplified by attention “capture” by faces. More specifically, two account of attention specificity, i.e., “automaticity” vs. a “channel” account are contrasted. Finally, evidence for a limit in face processing is summarised at the end of this section.

2.2.1. Perceptual selectivity

A matter of intense debate in the current research on face perception is related to the question of whether mechanisms involved in the perception of a face are domain-specific, i.e., activated solely by visual presentations of face stimuli (e.g., Kanwisher et al., 1997; Kanwisher & Moscovitch, 2000), or whether those mechanisms can be activated to the same or a similar extent by visual presentations of other objects (e.g., Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002; Rossion, Kung, & Tarr, 2004; Tarr & Gauthier, 2000). Empirical evidence for perceptual selectivity stems from several lines of research.

First, some support for the assumption that faces might be special has been derived from the “face-inversion effect”, initially described by Yin (1969). Accordingly, image inversion disproportionally affects recognition of faces in contrast to other objects (for a review, cf. Valentine, 1988; Rossion, 2008; for an alternative "expertise" explanation of the face inversion effect, cf. Diamond & Carey, 1986), suggesting that face perception is specifically depending on upright image orientation.

Second, functional imaging evidence supported face selectivity by revealing that faces are partly being processed in a brain region specifically dedicated for the processing of faces, the “fusiform face area” (FFA; cf. Eger, Schweinberger, Dolan, & Henson, 2005; Grill-Spector, Knouf, & Kanwisher, 2004; Haxby, Hoffman, & Gobbini, 2000; Kanwisher et al., 1997; Wojciulik, Kanwisher, & Driver, 1998; Yi, Kelley, Marois, & Chun, 2006). Similarly, electrophysiological studies identified event-related potential components responding selectively to faces: the N170, an occipito-temporal negative component around 150-200 ms, and the N250r, a greater negativity to repeated vs. unrepeated faces between 200 and 350 ms in occipito-temporal regions. It has to be noted, though, that face selectivity of the FFA and the N170 (and recently the N250r, cf. Engst, Martin-Loeches, & Sommer, 2006) has been challenged. For example, functional imaging showed that objects of great expertise could elicit similar activations in the FFA (Rossion, Gauthier et al., 2002; Rossion et al., 2004), and similar electrophysiological evidence was reported for the N170 (Rossion, Gauthier et al., 2002). Likewise, N170 amplitudes were recently found to be indistinguishable for faces and car fronts (Schweinberger, Huddy, & Burton, 2004), suggesting that this component may be sensitive to, but not selective for, faces.

Finally, neuropsychological research on patients with brain lesions suggested a double dissociation of face vs. object recognition. For instance, prosopagnosic patients exhibited a deficit in overtly recognising familiar faces, even when those were highly familiar (e.g., Tranel & Damasio, 1985). In some cases these deficits could be specific to the extent that these patients did not show problems in learning or identifying other objects (Duchaine, Dingle, Butterworth, & Nakayama, 2004; Henke, Schweinberger, Grigo, Klos, & Sommer, 1998). Other patients, selectively suffering from object agnosia, experienced severe impairments in object recognition, while face recognition was largely intact (Moscovitch, Winocur, & Behrmann, 1997). These findings support assumptions of discrete neural mechanisms underlying object and face processing.

2.2.2. Attentional selectivity

Beyond this putative face-specific *perceptual* mechanism, there is also evidence suggesting the existence of a face-specific *attentional* mechanism. For example, it has been shown that emotionally valent stimuli can be processed very effectively, and that emotional significance might even be encoded preattentively by a subcortical circuit involving the amygdala (Compton, 2003). In particular, fearful (Fox et al., 2000; Fox, Russo, & Georgiou, 2005) and angry (Mogg & Bradley, 1999; Öhman, Lundqvist, & Esteves, 2001) faces were found to very effectively attract, or “capture” attention. However, assuming a specific processing system for faces, as discussed above, the power to attract attention might not be limited to emotional faces, but is likely to extend to neutral faces, as well. In line with this idea, a recent study reported greater attention capture from emotional faces than from emotional words (Beall & Herbert, 2008), suggesting that faces might be more effective in capturing attention than other types of stimuli (i.e., words). It is therefore plausible to assume an additional face advantage that might be independent from emotional content. In line with this assumption, research on various aspects of attention, and using a range of different paradigms, reported an advantage, or “attention bias” for faces.

As an example for attentional selectivity, in the following section I will introduce the different lines of evidence supporting the idea that faces may be special in their ability to “capture” attention.

2.2.3. Attention orientation to faces

It has recently been demonstrated that faces have an advantage when competing with other stimuli for attention resources. For instance, changes in faces are detected more accurately and rapidly than changes in other objects (Ro, Russell, & Lavie, 2001). Similarly, inhibition of return (longer eye-saccade latencies to a location at which a face had been displayed recently vs. a location at which a concurrent non-face object had been presented) was observed to face cue locations, indicating that initial attention was on a face, and not on the non-face location (Theeuwes & Van der Stigchel, 2006).

Attentional "pop out" effects for faces were tested in visual search paradigms. In these paradigms, participants are required to detect a target among varying numbers of distractors. When the response time to a target is independent of the number of distractors in the display, the target is assumed to pop out (Treisman & Gelade, 1980). It has been shown that line-drawings of faces do not cause pop out (Nothdurft, 1993), and, similarly, photos of upright faces do not cause pop out when distractors were inverted faces, and vice versa (Brown, Huey, & Findlay, 1997). In contrast, when a photo of a upright human face target had to be detected in an array of non-face distractors (arrays contained of up to 64 heterogeneous photographs of objects), search speed in "face present" trials was largely unaffected by set size, indicating parallel search (Hershler & Hochstein, 2005), and thus a face pop out. Hershler and colleagues took this as evidence for the existence of a "high-level visual system with the ability to process and generalise faces in parallel over the visual field" (p. 1716). In contrast to earlier experiments, a pop out effect was also found for line drawings of faces, presented either among line-drawn houses or cars, but not for house or car targets among face distractors. Moreover, neither animal faces nor scrambled faces caused a pop out, the latter making low-level explanations for the pop out found for faces unlikely. Finally, the authors found pop out not only for intact faces, but, although slightly reduced, also for a face's inner features only, and for a face's outer features only. Though the authors argue that this result implies "strong evidence that the rapid visual search for faces is indeed based on a high level holistic facial percept" (p. 1720), the pop out in this last experiment might alternatively have been created by the image editing per se, as all distractor images were unedited (cf. Hershler & Hochstein, 2005 Fig. 5) . It has been suggested by others (VanRullen, 2006), that attention capture by faces in this study might even be entirely explained by low-level confounds – specifically the Fourier amplitude spectrum – which differed between faces and the other objects and might have caused the attention capture effects (but see Hershler & Hochstein, 2006).

Another general problem inherent in visual search paradigms is the fact that the defining attribute of a stimulus is also the attribute that is reported (Langton, Law, Burton, & Schweinberger, 2008), such that participants can (and most likely will) prepare to search for certain stimuli (i.e., faces). In contrast, true attention capture should be independent of this readiness, and should be defined as attention capture by an attribute that is independent of both the defining and the reported attribute of a stimulus (Yantis, 1993). Langton and colleagues tested the distracting influence of an irrelevant face in a display when participants searched for another target object (butterfly) in a circular array of 6 items. The circular arrangement of items equated the stimulus eccentricity in contrast to the experiments by Hershler et al. (2005), in which stimulus eccentricities inevitably varied with set sizes. Langton et al. (2008) found an increase in response times in butterfly detection when upright faces were present compared to when upright faces were absent. Critically, no such effect was observed for inverted faces among inverted items, suggesting that upright, but not inverted faces captured attention (but see Bindemann & Burton, 2008).

Recently, it has been shown that the attention bias to faces can be controlled endogenously to some extent (Bindemann, Burton, Langton, Schweinberger, & Doherty, 2007). In a modified spatial cueing task (cf. Posner, Snyder, & Davidson, 1980), participants saw cue displays containing a face and a non-face at opposing positions right and left of a fixation. Subsequently, a target stimulus appeared at one of the cue locations, and participants made speeded responses according to the target position. Critically, cue validity was manipulated, in that a cue was correctly predicting the target in 25/75%, or 50% of trials. In 50% trials, participants were faster when the target appeared at the face cue location, replicating the attention bias to faces. However, when participants were informed that it was beneficial to ignore the face because the target will be more likely to appear at the object cue location (i.e., in 25/75% trials), response times were faster for object cued locations. This suggests the existence of two separate effects, one exogenous attention capture effect for faces, and one endogenous orienting effect under voluntary control.

In a recent paper, Bindemann et al. (2008) observed similar face advantages for attention capture not only for upright, but also for inverted faces. While this is clearly in contrast to the results reported by Langton (2008), it might partly explain the lack of attention capture in visual search paradigms using inverted faces as distractors (e.g., Nothdurft, 1993).

Faces even showed an advantage when embedded in an everyday natural scene (Fletcher-Watson, Findlay, Leekam, & Benson, 2008). Participants were simultaneously presented with a pair of natural scenes, one of them containing a person (body and face). Strikingly, analyses of eye movements revealed that a face region was viewed for a disproportionate long time, when considering their relatively small size in comparison to, for example, the body or object sizes within the scenes. The authors claimed that "human figures and their faces are subject to special perceptual attention" (p. 582), when they are presented as a part of a natural scene.

In sum, while earlier studies often failed to find pop out effects by faces, possibly due to the use of line-drawn faces, or perceptually too similar distractors, more recent studies demonstrated reasonable evidence for a face advantage in capturing attention over other object categories. However, the orienting of attention to a stimulus (location) is only one function of attention. Indeed, faces do not only seem to have a special ability to attract attention, but also to be preferentially processed in conditions of massively restricted availability of attentional resources. Some authors have taken this as evidence for automatic face processing. I will review this evidence in the next section.

2.2.4. Automatic face processing

The suggestion of automatic, and mandatory, face processing in part resulted from the discovery of a brain region that responds preferably to presentations of faces, the FFA (see above). As detailed below, this has been taken to suggest automaticity in face processing by some authors.

In an early study on face and name identification, Young and colleagues (1986) tested interference from irrelevant famous name flankers on famous faces and vice versa, when participants performed either a naming task, or a categorisation task. Names were presented alongside faces in a "speech bubble", and name-face pairs were either from the same person, or semantically related (i.e., same occupation), or unrelated (i.e., different occupation), or face or name targets were presented without a flanker (i.e., “face only” or “name only”, for the face and the name condition, respectively). As one key finding of this study, interference occurred from irrelevant face flankers on name categorisation in terms of slower responses in “unrelated flanker” vs. “face only” conditions. In contrast, irrelevant name flankers caused no interference on face categorisation. This pattern suggests that information relevant for face categorisation is encoded rapidly from face images, and it might thus be interpreted as tentatively supporting an account of automatic processing of faces (cf. Jackson & Raymond, 2006). Similarly, Ellis (1990) found that participants were faster to classify familiar (famous) faces as being famous after seeing the same images in a previous prime phase. Strikingly, this repetition priming effect was observed even when the initial prime task did not require participants to encode identity information (i.e., when they instead performed sex classifications). This suggested that identity information is automatically encoded from famous faces, even when irrelevant for the task at hand.

More recently, Lavie et al. (2003) investigated the distracting influence of irrelevant famous face flankers on centrally presented names, while manipulating perceptual load in a name categorisation task (occupation judgments) by increasing the set size in which a name could appear from 1 item (famous name only, “low load”) up to 8 items (famous name among 7 strings of random letters, “high load”). Face-name pairs were either from the same person (“congruent”) or from the opposite category (“incongruent”). Critically, even at largest set sizes of 8 items (Experiment 3) an influence of the distractor face on the name classification was present, and of comparable size as found for smaller set sizes. By contrast, in control experiments the distracting influence of an *object* image presented laterally to an object name was eliminated at a set size of 6. The authors took this as “perhaps the strongest direct behavioural evidence for the suggestion that face processing may be automatic and mandatory” (p. 514).

In sum, the studies reported so far provided evidence for a special status of faces in situations of limited availability of attentional resources. However, this does not necessarily favour *automaticity* of face processing, since automatic processing is independent of capacity limitations (Palermo & Rhodes, 2007; Schneider & Shiffrin, 1977). More specifically, true automatic processing of faces does only prevail if faces are being processed in an especially rapid, non-conscious, mandatory, and capacity-free fashion (Palermo & Rhodes, 2007).

Alternatively, the above-mentioned findings could be explained by assuming a face-specific attention resource that exists independent from general attention resources. Actually, Lavie and co-workers (2003) acknowledged the possible existence of a capacity limit for face processing (though in their study this was not directly tested). However, assuming the existence of a capacity limit would rather speak for a face-specific attention resource than for an automatic face processing account. Accordingly, I will outline evidence from studies supporting a face-specific, but capacity-limited attention resource in the following section, starting with recently controversially discussed evidence from rapid serial visual presentation (RSVP) paradigms.

2.2.5. A Channel account in face processing: Evidence from Attentional Blink

In RSVP paradigms, participants are presented with a stream of briefly presented objects in quick succession, among which they are required to detect two target stimuli (T1, T2) displayed within a stream of distractors (Shapiro & Arnell, 1992). Attentional blink (AB) is defined by a performance reduction in detecting T2 targets when these occur within a critical time interval after T1 presentation. More specifically, T2 targets are usually missed more often when they are presented shorter than ~500 ms after T1 targets.

In line with the idea of separate processing channels for letters and faces, Awh et al. (2004) reported an AB to a subsequent letter target (T2), when previously a letter target (T1) had to be identified. In contrast, when a face occurred as a T2 target, the authors found no AB effect, suggesting intact face processing even under this condition of massively restricted temporal attention. The authors suggested the existence of separate channels of attention for face and letter processing and argued against a central bottleneck in visual perception. Crucially, though, the authors found that presenting faces as *both* T1 and T2 targets resulted in an *intact* AB effect. Accordingly, a T1 face target seemed to have occupied the face attention channel, and thus prevented the processing of a subsequently presented face when the time interval fell into the critical 500 ms. Awh and co-workers replicated this pattern of results when using “greebles” instead of faces at either T1, or T2, or both T1 and T2 target positions. Greebles, like faces, are objects that are thought to evoke configural processing (Farah, Wilson, Drain, & Tanaka, 1998). Consistently, Awh et al. argued that configural processing of faces and greebles might be carried out in a “perceptual channel" separate from the channel used for rather feature-based processing of, for example, letters (for a similar account, cf. Palermo & Rhodes, 2002).

However, this idea has only partly been supported by two recent studies (Einhäuser, Koch, & Makeig, 2007; Landau & Bentin, 2008). Landau & Bentin (2008) intended to directly replicate the results of Awh and colleagues (2004), but used objects targets (watches, flowers) instead of letters targets, as the absence of attentional blink in Awh et al. might have reflected differences in the perceptual complexity between these stimulus classes (Landau & Bentin, 2008). Most relevantly for this thesis, the authors reported initial evidence for a double dissociation between faces and objects in terms of the presence or absence of an AB effect. Replicating Awh et al. (2004), T1 objects caused an AB for T2 objects, but not for T2 faces. Moreover, T1 faces caused an AB for T2 faces, but not for T2 objects (Experiment 2). This pattern, similarly reported by Einhäuser et al. (2007), is in line with the assumption of separate attention modules, or channels, for object and face processing. Interestingly, the observed AB reduction was not a "within-category" effect, in that AB might be extinguished when both T1 and T2 were of the same stimulus category, i.e., both watches, or both cars. In contrast, T1 cars caused reliable AB for T2 watches (Experiment 3), although this effect was smaller than the AB observed for within-category AB in the experiments 1 and 2. So far, the result supported separate attentional resources, with cars and watches being processed within the same (non-face) attention channel, whereas faces are being processed in a separate channel, respectively. However, in a follow-up Experiment (Experiment 4) a more demanding task (high attention load) led to an AB effect for T1 faces not only on T2 faces (replicating previous capacity limitations for face processing), but also on T2 objects (watches), suggesting that object processing is reduced under high demands in the putative face channel. According to Landau & Bentin (2008), this last finding corroborates the idea of clearly separated, independent, attention channels for faces and objects. As a conclusion, the authors attribute the face detection advantage in the RSVP paradigm to result from perceptual salience, possibly in combination with higher expertise to faces than objects, rather than from the existence of separate attention channels, as suggested by Awh et al. (2004).

Similarly, it has been found that the degree of familiarity with a face (i.e., the degree of expertise with a specific face) might modulate, or even cause, the AB reduction effects for faces. Jackson & Raymond (2006) found intact AB for unfamiliar and somewhat familiar faces, and found the AB reduction effect only to be present for highly familiar faces. The authors contradicted the idea of a face-specific, or configural, processing channel, and instead argued that high familiarity of faces decreases the attentional demands, which then leads to facilitated processing of T2 faces. However, this strong claim is not only in contrast to the study by Awh et al. (2004), which according to the authors might be explained by methodological shortcomings of that study (i.e., using only 3 different face stimuli), but is also not supported by the recent study by Landau (2008), who reported AB effect despite using unfamiliar faces.

As a conclusion, although the results from RSVP paradigms may not be consistent in supporting a separate face channel, they also do not convincingly refute it. The results are certainly not entirely explained by stimulus familiarity alone, as has been suggested by Jackson and Raymond (2006). However, conclusions from RSVP evidence may be limited since this paradigm does not test selective attention by simultaneous presentation of the stimuli. In contrast, the observed AB may rather be attributed to the processing speed of stimuli in subsequent, though rapid, presentations. In the next chapter, I will review evidence from studies suggesting capacity limits for faces in selective attention paradigms.

2.2.6. Capacity limits of face processing

Although controversial, RSVP evidence seemed to indicate that separate channels carry out face and object processing. Moreover, these channels may reach a *temporal* attention limit when two items, processed within the same channel, are presented in quick succession. However, other recent studies revealed a similar processing limit of *spatial* selective attention, when two or more faces were presented simultaneously.

In an initial study, Palermo and Rhodes (2002) tested immediate recognition of face parts. They presented composite faces (interchanging eyes, nose, mouth, and face outlines) either alone (“full attention”), or laterally flanked by two intact faces (“divided attention” or “full attention with flankers”). Subsequently, foil faces were presented, containing exactly one feature from the previous target face, which participants had to identify. In the “divided attention” condition, participants were additionally required to match the flanker face identities. In four experiments, all stimuli were presented either upright or inverted. While under full attention conditions participants were more accurate in encoding from upright face targets than isolated parts targets ("holistic encoding advantage"), this pattern was absent in divided attention conditions, suggesting that the attention manipulation disrupted holistic encoding of upright faces. For inverted targets, no holistic encoding advantage was found under any attention condition. Crucially, target face processing might have been disrupted by a capacity limit for holistic processing that was fully consumed by matching two (upright) faces in the divided attention task. Consistent with this assumption, a holistic encoding advantage was replicated for upright faces, when inverted flankers were used. Overall, the disruption of holistic encoding when upright flanker faces had to be matched strongly suggests that face processing requires attention, rather than being automatic. However, the absence of this disruption when inverted faces were used might be interpreted in favour of a "face recognition module", (Palermo & Rhodes, 2002), dedicated for holistic encoding, and probably specific or at least well suited for upright face processing. Moreover, this face recognition module is obviously capacity-limited, such that it was exhausted by simultaneous processing of two faces.

Although these results in favour of a capacity-limited face recognition module were promising, the contributions to attention effects from this paradigm are not clear, as the task involved a memory component. Although only for a brief period of time, participants had to memorise a face in great detail, and to compare features of this face with a subsequently presented face. Thus, one cannot be sure whether the observed capacity limit was caused by the simultaneous presentation of several faces, or whether it could alternatively reflect capacity limitations of working memory. Moreover, stimuli were presented for a rather long duration (1.5 s). In principle, this might have enabled participants to sequentially process target and distractors.

However, despite choosing an alternative approach that involved no memory requirements and shorter stimulus presentation duration (200 ms), Jenkins and coworkers (2003) substantiated these initial findings. Participants classified centrally presented famous names according to occupation, while an irrelevant congruent or incongruent face distractor flanked these names. In contrast to Lavie (2003), a second (neutral) distractor sometimes appeared on the respective other side of the first distractor, being either a second face, or a non- (recognisable) face (phase-shifted face in Experiment 1, inverted face in Experiment 2, objects in Experiments 3/4). Interference from famous face distractors was found to a similar extent irrespective of whether the distractor was presented alone (without neutral distractor), or together with a non-face distractor. Critically, and in line with Parlermo & Rhodes (2002), the distracting influence was consistently and significantly diluted when a second upright face became the neutral distractor. Moreover, the authors were able to show that distractor interference from an irrelevant object was diluted by basically all types of distractors (objects, upright faces, inverted and phase-shifted faces) to the same extent, thus suggesting that the capacity limit might be more specific to upright faces than to other object categories. As a consequence, it might be impossible to suppress processing of a specific face unless an additional face is being presented simultaneously.

In a related study, Bindemann and co-workers (2005) tested processing of a task-irrelevant distractor face in the presence of a task-relevant face vs. non-face target. In sum, the authors again found diluted interference from famous face or name distractors on famous face or name targets consistently when a face distractor flanked a face target, i.e., when two faces appeared simultaneously in the display. In addition, this finding was replicated using a range of different tasks (sex decision, occupation decision, nationality decision) and stimulus classes (names, faces, flags). Consequently, the authors suggested the existence of an attention resource, limiting simultaneous processing to one face at a time.

In spite of the overall support of a capacity limit in face processing reported by these studies, the exact locus of any bottleneck in face processing is still difficult to specify. Some kinds of information, i.e., sex, occupation, and nationality may not be extracted from a task-irrelevant face in presence of a task-relevant face target. However, this does not rule out some processing of the face distractors under these conditions. Bindemann (2007) suggested that repetition priming might be a highly sensitive measure for residual processing (cf. also Driver & Tipper, 1989). In the next section, I will introduce the concept of repetition priming in greater detail by summarising behavioural and electrophysiological evidence for repetition priming from – presumably – unattended faces.

2.3. Repetition Priming by faces

Priming refers to a change in speed, bias, or accuracy, after prior experience with the same or a related stimulus (Henson, 2003), and is considered as a measure of implicit memory. In contrast to explicit memory, which can be tested directly in recall or recognition paradigms, implicit memory is typically investigated in indirect memory task that make no overt reference to the previous experience with the stimulus. Evidence for this dissociation is that explicit memory is massively impaired in people with amnesia, while implicit memory often remains equivalent to controls (Warrington & Weiskrantz, 1974). When a stimulus has recently been encountered (prime presentation), participants typically respond faster and more accurately on a second (probe) presentation of that identical stimulus compared to when they had not seen it before. This effect has been referred to as “repetition priming” (e.g., Ellis et al., 1990), or “identity priming” (Burton, Bruce, & Johnston, 1990). Repetition priming by faces can be obtained when face primes were judged according to familiarity, but not when judged according to sex or expression (Ellis et al., 1990; but see Goshen-Gottstein & Ganel, 2000; Wiese, Schweinberger, & Neumann, 2008), and has been suggested to require recognition of a familiar prime face to proceed spontaneous, but not prompted (Brunas-Wagstaff, Young, & Ellis, 1992).

However, priming is considered as a side effect of the normal operation of perceptual systems (Henson, 2003), and has been used as a sensitive tool for investigating the different stages in the processing of visual objects – particularly in studies employing neuroimaging or electroencephalographic (EEG) methods. A short overview of how priming can be explained within a model of face recognition is given in the next section, with added empirical evidence from behavioural and electrophysiological studies on repetition priming in the face domain.

2.3.1. Repetition priming in an interactive activation model of face recognition

Bruce and Young (1986) developed the now classical functional model of face recognition in which face recognition mainly proceeds via three distinct subsequent stages. In the following years, Burton and co-workers (Burton, Bruce, & Hancock, 1999; Burton et al., 1990; Burton, Young, Bruce, Johnston, & Ellis, 1991) extended this account by implementing an interactive activation and competition (IAC) network.

This model (cf. Fig. 1) suggested the existence of three pools of units primarily involved in face recognition: face recognition units (FRUs), associated with classification of a *face*, person identity nodes (PINs), associated with classification of a *person*, and semantic information units (SIUs), coding information about known individuals (Burton et al., 1999). While the first two pools (FRUs and PINs) already existed in a similar way in the Bruce & Young model, semantic information units (SIUs) were newly introduced with the IAC account and are thought to store semantic information about familiar persons. In contrast, Bruce and Young (1986) had assumed that semantic information is stored in the PINs (and in part in the rather vaguely defined „cognitive system“ unit). The IAC model proposes PINs to be *nodes*, allowing access to stored information, rather than *units,* which store information. Critically, one PIN can be connected to more than one SIU, and SIUs can be shared by several PINs, which allows efficient storing of information.

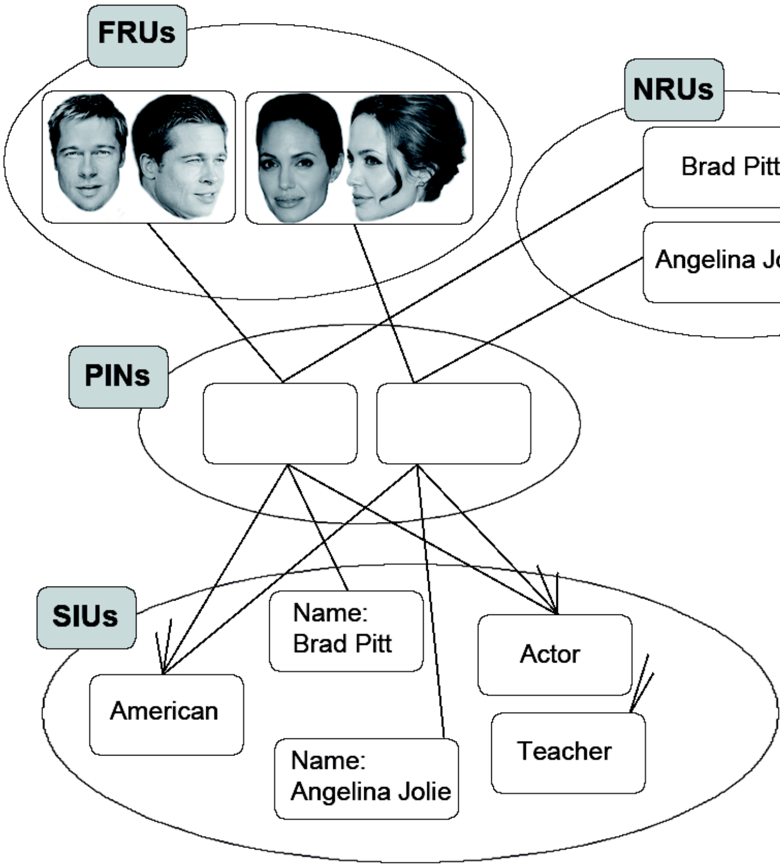

Figure 1: IAC core units involved in face recognition, and name recognition units (NRUs) (adapted from Burton, Bruce, & Johnston, 1990).

Of particular relevance for the current thesis, the authors validated the IAC approach by modelling processes reflecting both repetition and semantic priming for faces. Accordingly, semantic priming, i.e., the facilitation in processing a stimulus when preceded by a semantically related stimulus (e.g., Bruce & Valentine, 1985, 1986), reflects the spreading activation from a PIN to connected SIUs. These activated SIUs in turn pass the activation to other connected PINs. In Figure 1, the PIN of Brad Pitt, activated by either the FRU or the name recognition unit (NRU) of Brad Pitt, could activate the SIUs “actor” and “American”, which in turn pass the activation to the PIN of Angelina Jolie. Thus, the face or the name of Brad Pitt semantically primes Angelina Jolie. In contrast, repetition priming by faces reflects the strengthening of connections between FRUs and PINs of one specific person. For example, an encounter with the face of Angelina Jolie will cause increasing connection strength between the FRU and the PIN of Angelina Jolie. At a repeated presentation, a recognition threshold at PIN level will be reached faster, thus causing the performance benefit associated with repetition priming.

The model predicts a fast decay of semantic priming, caused not only by duration, but also by the presentation of intervening familiar faces. Accordingly, the necessity of seeing another famous (but unrelated) face causes massive activation reduction to a PIN of a previously presented face. Semantic priming should also occur both within- and across-domain, while identity priming is assumed to occur only within-domain. For example, while a written name „Angelina Jolie“ should semantically prime the face of Brad Pitt, identity priming from the name “Brad Pitt” on the face of Brad Pitt is not supposed to emerge, according to the IAC model. This pattern was repeatedly found in empirical work (Bruce & Valentine, 1985, 1986; Young, Hellawell, & Dehaan, 1988).

Event-related potentials (ERPs) provide a useful tool to investigate timing of cognitive processes underlying repetition effects (e.g., priming). In the next section, I will describe the most relevant ERP components associated with face repetition priming.

2.3.2. Event-related potential correlates of repetition priming in face perception

Event-related potentials (ERPs) are voltage fluctuations that are associated with, or time-locked to, an occurrence of an event, for example, the presentation of a specific stimulus type (Picton et al., 2000; Wiese & Schweinberger, 2008). Besides providing fine-grained chronometric measures of neural processes, measuring ERPs includes the additional advantage that no overt response to an event is required for analyses (Wiese & Schweinberger, 2008). Studies that investigated ERP repetition effects for faces frequently focussed on the three ERP components described below.

N170

The N170 is a prominent negative response over occipito-temporal areas, peaking approximately 170 ms after stimulus onset, and is elicited by faces and other visual stimuli, although typically largely reduced for non-faces in comparison to faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Bentin et al., 2007; Rossion & Jacques, 2008; Schweinberger & Burton, 2003). The N170 is usually thought to reflect relatively early processes in face perception related to the detection of a facial pattern, to the structural encoding of faces, or both (Bentin et al., 1996; Eimer & McCarthy, 1999; Engst et al., 2006). The N170 was found independent of face familiarity (Bentin & Deouell, 2000; but see Caharel et al., 2002) and it occurs irrespective of whether faces are relevant or irrelevant to a task (Bentin & Deouell, 2000). The N170 has been suggested to be domain (i.e., face-) specific (Bentin et al., 2007; Carmel & Bentin, 2002), although alternative interpretations assumed the N170 related to expertise (Rossion, Curran, & Gauthier, 2002; Rossion, Gauthier et al., 2002; Rossion et al., 2000), or even to be a low-level artefact, reflecting the perceptual homogeneity of the stimulus category of faces (Thierry, Martin, Downing, & Pegna, 2007; but see Rossion & Jacques, 2008). Paralleling this debate, evidence for the sensitivity of the N170 to face *repetitions* is also controversial: While face repetitions did not appear to affect N170 amplitude in a large number of studies (Cooper, Harvey, Lavidor, & Schweinberger, 2007; Eimer, 2000c; Engst et al., 2006; Schweinberger, Pickering, Burton, & Kaufmann, 2002), other studies reported an effect of repetition on N170 amplitude (Heisz, Watter, & Shedden, 2006; Itier & Taylor, 2002, 2004a; Jemel, Pisani, Calabria, Crommelinck, & Bruyer, 2003; Jemel, Pisani, Rousselle, Crommelinck, & Bruyer, 2005; Wiese et al., 2008).

N250r

The N250r is an electrophysiological correlate more consistently found for immediate face (or name) repetitions (Begleiter, Porjesz, & Wang, 1995; Engst et al., 2006; Henson et al., 2003; Martin-Loeches, Sommer, & Hinojosa, 2005; Pfütze, Sommer, & Schweinberger, 2002; Pickering & Schweinberger, 2003; Schweinberger et al., 2004; Schweinberger, Pfütze, & Sommer, 1995; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002). This component refers to a relatively more negative ERP waveform for repeated as compared to unrepeated faces, a difference which typically peaks between 230 and 330 ms over right inferior temporal regions. N250r effects have been repeatedly shown to be larger for familiar than unfamiliar face repetitions (Begleiter et al., 1995; Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Pfütze et al., 2002; Schweinberger et al., 1995), and to be rather short lasting, deteriorating after 2-4 intervening items. The N250r was consequently interpreted as a transient activation of facial representation for face recognition (Itier & Taylor, 2004a), or as a transient activation of object representations, with largest responses for upright faces (Schweinberger, Kaufmann, Moratti, Keil, & Burton, 2007). Recently, face-specificity of the N250r has been challenged. Engst and co-workers (2006) reported N250r effects not only to emerge for face repetitions, but also for repetitions of familiar buildings. The authors claimed that N250r topographies and thus the neural generators were identical for faces and buildings. It must be noted, though, that N250r amplitudes in that study were still clearly larger for faces than for buildings, and that amplitudes peaked 30 ms later for buildings than for faces, showing that the underlying mechanisms are at least quantitatively different for faces and buildings. In addition, the N250r has been shown to reflect some image specificity. N250r effects have been found to be twice the magnitude for image-specific face priming (i.e., using identical images for prime and probe presentations) than for priming by a different image from the same (famous) person (Cooper et al., 2007). However, such image specific effects cannot completely explain the N250r. Although image specific effects were replicated, Bindemann and co-workers (2008) demonstrated that N250r could be elicited equivalently by identical priming and priming by a geometric distorted (horizontally or vertically stretched) face, ruling out an explanation of the N250r as simply reflecting visual overlap of prime and probe image. In sum, the sensitivity of the N250r for familiarity in combination with the partial image specificity suggests that N250r could reflect a stimulus-triggered *access* to stored facial representations rather than the activation of the corresponding FRU per se (Bindemann et al., 2008).

N400

Finally, the N400 (Kutas & Hillyard, 1980) is a negative ERP at centro-parietal regions, and may be the best-known ERP that is sensitive to priming (for a review, cf. Kutas & Federmeier, 2000). This relatively late ERP has been initially described in the field of word recognition and is thought to be related to the semantic integration of the current stimulus into the preceding context. Heil & Rolke (2004) reported N400 repetition effects not only for attended, but also for unattended words, despite the absence of behavioural priming in the unattended condition. This finding emphasises the sensitivity of ERPs in revealing repetition effects, and distractor processing in contrast to behavioural measures such as response times (see also Schweinberger et al., 1995; but see Brown & Hagoort, 1993).

For faces, an analogous deflection was observed which is found affected by familiarity (Barrett, Rugg, & Perrett, 1988; Eimer, 2000c; Schweinberger et al., 1995) and has been interpreted as semantic activity involved in the identification of familiar faces (Bentin & Deouell, 2000; but see Debruille, Pineda, & Renault, 1996 for the alternative approach, N400 elicited by faces reflected knowledge-inhibition). Similarly, *repetitions* of faces have also been shown to modulate N400-like components (Bentin & McCarthy, 1994; Cooper et al., 2007; Henson et al., 2003; Schweinberger, Pickering, Burton et al., 2002). Accordingly, the N400 was suggested to represent activation at the level of person identity nodes (PINs) (Bentin & Deouell, 2000; Eimer, 2000c), likely reflecting semantic knowledge activation (Cooper et al., 2007; Pickering & Schweinberger, 2003) and an index of familiarity with a specific face (Eimer, 2000c; Joyce & Kutas, 2005).

2.4. Neural correlates of attention in face repetition priming

As detailed in the previous sections, repetition priming and its neural correlates may provide a highly sensitive tool to investigate face processing on separate stages during the face recognition process. In this section, I will demonstrate that repetition priming is also highly applicable for testing face processing when faces are *irrelevant* to an ongoing task, and thus assumed to be unattended. The rationale of these studies typically included the manipulation of attention that participants could devote to a prime face, and to test subsequent repetition effects from probe faces.

In a behavioural study, Jenkins and co-workers (2002) tested explicit and implicit memory for famous faces that have been task-irrelevant during their first occurrence. Participants were presented with red vs. blue letter strings, consisting of 6 different letters (i.e., “KMHNZL”), which were superimposed on images of famous distractor faces. Participants were given either a simple colour detection task (decide whether letter strings were red vs. blue), or a more demanding letter identification task (decide whether an X or N was among the letters). Following the letter search / colour detection task, participants performed a surprise (explicit) name recognition test, in which they indicated whether a presented name belonged to a face that had been shown as a previous task-irrelevant face. In line with Perceptual Load Theory, participants were more accurate for faces that were presented under the low load condition than for those presented under the high load condition. In striking contrast, performance for a subsequent (implicit) repetition priming task was completely unaffected by the perceptual load manipulation. Instead, substantial and equivalent repetition priming was observed from faces presented under both high and low load.

This finding not only demonstrates relatively deep processing (as priming was observed even when an image change between prime and probe phase occurred) under high load, suggesting the absence of general attention resources for implicit processing of faces, but also shows the sensitivity of repetition priming as a tool to investigate distractor face processing, when compared to explicit tests.

In a recent study, Bindemann and co-workers (2007) tested attentional capacity limits for faces by measuring repetition priming from task-irrelevant face distractors flanking either face or non-face targets. In a probe phase, faces that were either presented before as i) targets, ii) face flankers, iii) non-face flankers, or that were not seen before (famous or unfamiliar), had to be judged according to familiarity. No priming was observed from face flankers, while intact priming occurred from non-face flankers. This is in line with findings that suggested a capacity limit of one face at a time (Bindemann et al., 2005; Palermo & Rhodes, 2002), as detailed above.

Although numerous studies examined electrophysiological correlates of repetition priming in face recognition, surprisingly little is known about the influence of attention to prime and/or probe faces on ERP repetition effects. In one relevant study, Eimer et al. (2000c, Part II) presented familiar faces, unfamiliar faces, and houses, while a 5-character alphanumeric string was centrally presented superimposed on faces and houses. In the “attended” condition, participants had to detect immediate face or house repetitions, whereas in the “unattended” condition, they had to detect a single digit in the 5-character string. However, the authors in this study were interested in analysing familiarity rather than repetition modulations, and thus reported N400 familiarity modulations for attended but not for unattended faces. Hence, the influence of attention on ERP *repetition effects*, which would require contrasting repeated vs. unrepeated faces, was not investigated in this study. Two recent studies (Martens, Schweinberger, Kiefer, & Burton, 2006; Trenner, Schweinberger, Jentzsch, & Sommer, 2004) reported larger N250r amplitudes in a direct matching task (that is, both prime and immediately repeated probe presentations were attended and task relevant) as compared to an indirect priming task (only probe presentations were relevant for the task). Accordingly, the N250r was assumed not to reflect automatic aspects of face processing, but rather to be modulated by either attention or task relevance.

Critically, though, all three studies intermixed aspects of task-relevance and attention. The authors expected task-irrelevant items not to be attended by the participants, whereas rendering an item relevant for a task automatically causes it to be attended. The Perceptual Load Theory (Lavie, 1995), however, does not necessarily support this assumption. For example, even though being task-irrelevant, attention might have “spilled over” to faces in both the “indirect task” (Martens et al., 2006; Trenner et al., 2004) and the “detect digits” (Eimer, 2000c) conditions, provided that attentional capacity was not fully consumed by the primary task. This has not been controlled for in either study. In conclusion, the fact that task-relevance and attention were confounded makes the results obtained in the studies reported here difficult to interpret with respect to the contribution of attention. It has to be noted that none of these studies was primarily interested in testing ERP repetition effects from attended vs. unattended faces. So far, no direct investigation has been carried out testing effects of *perceptual load* manipulations to prime stimuli on repetition-sensitive ERP components.

Although evidence on the influence of attention on ERP repetition effects is rare, a number of neuroimaging studies controversially discussed this topic. „Repetition suppression“, a decreased neural response in brain regions associated with the processing of the respective stimulus type, is typically observed for repetitions of stimuli, even when several intervening different stimuli occur. However, in the functional magnetic resonance imaging (fMRI) literature, it is still controversial whether attention to the initial and repeated presentation is required for this effect to emerge (Henson & Mouchlianitis, 2007). Some studies failed to find repetition suppression, when the initial face or scene presentation was unattended (Eger, Henson, Driver, & Dolan, 2004; Yi et al., 2006; Yi et al., 2004). In contrast, Bentley and co-workers (2003) reported repetition suppression even when faces were ignored at both initial and repeated presentation.

In a related recent study, Henson & Mouchlianitis (2007) manipulated attention to both initial and repeated presentations of faces and houses, presented simultaneously in the left and right visual hemifield. Participants were instructed to attend to one hemifield only and make house vs. face categorizations to those stimuli, and to ignore the other hemifield. Repetitions could emerge in the respective attended or the unattended hemifield. The authors observed no repetition suppression from houses or faces that were unattended at either initial, repeated, or both initial and repeated presentations. Reliable repetition suppression was only observed when stimuli were attended at both presentations. The authors concluded that attention to both prime and probe presentations is required for repetition suppression to occur.

Strikingly, and acknowledged by the authors, *some* processing of ignored stimuli in this study was found. First, participants responded faster when both the ignored and the attended stimulus were of the same category (i.e., an ignored face, when a face was attended), an observation that might be related to the „bilateral redundancy gain“ (Mohr & Pulvermüller, 2002). Similarly, neural responses in the parahippocampal place area (PPA) were increased when two houses were presented as compared to an attended house flanked by a face. Moreover, PPA activity was found even when an ignored house flanked an attended face. Interestingly, the findings for the FFA were less consistent. The authors argued that perceptual load in this study might not have been sufficiently high to eliminate distractor processing entirely, as Perceptual Load is a continuum rather than a dichotomy. I will return to this aspect and this study later on in the discussion section.

In sum, ERP evidence for the influence of attention of face repetitions is largely absent, and related functional imaging evidence is inconsistent. Although it has been hypothesized that the controversial evidence from functional imaging studies may have resulted from differences in perceptual load of the respective studies (cf. Henson & Mouchlianitis, 2007), this has not yet been systematically investigated (but see Yi et al., 2004, for non-face stimuli).

2.5. Rationale of the current thesis

As detailed above, there is empirical evidence from several lines of research for face processing being “special”. Most relevantly, faces have repeatedly been shown to be processed under conditions of massively restricted attention resources. As discussed above, these findings can either be explained by an “automatic”, or by a “specific attention resource” account of face processing.

Considering the vast amount of behavioural research and functional imaging data on this topic, there is considerable lack of electrophysiological data on the influence of attention on repetition effects by faces. This is even more surprising, as ERPs have been proven very sensitive to stimulus repetitions, maybe even to a greater extent than behavioural priming. Moreover, due to the excellent time resolution of the EEG method, ERPs provide a useful tool for a more fine-grained analysis of the neural timing of attentional and repetition effects in stimulus processing. Applying electrophysiological measures would thus allow a more detailed insight into how attentional factors influence face processing at the processing stages that have been proposed by recent face recognition models. Finally, the few studies that investigated related questions are inconsistent with respect to the attention manipulation: Most studies simply assumed task-irrelevant items not to be attended as well which, as reasoned above, might be misleading.

Therefore, the aim of the current thesis was two-fold. One aim was to establish ERP correlates for repetitions of attended vs. unattended faces, while more carefully controlling for attention to the prime faces as derived from the Perceptual Load Theory. However, the main focus was on examining putative capacity limits for face processing of one face at a time, the existence of which would corroborate recent accounts of the “special attention resource” approach.

2.6. Empirical evidence

This thesis comprises of two research strands, consisting of 3 experiments each. These experiments conducted for this thesis were also published elsewhere (Neumann & Schweinberger, 2008; Neumann, Schweinberger, Wiese, & Burton, 2007) or are submitted for publication (Neumann & Schweinberger, submitted). This section gives a brief overview of rationale and the main results. I will give a more detailed summary and discussion of the results in the general discussion section.

2.6.1. Research strand 1

Strand 1 (Neumann et al., 2007) adapted a long-term repetition paradigm previously used by Bindemann and co-workers (2005), and measured behavioural correlates of interference, and both behavioural and neural correlates of repetition effects from task-irrelevant distractor faces that flanked centrally presented face or non-face targets (“central item types”: CITs). The three experiments directly approached the question of whether processing one face CIT exhausts the putative face-specific attention resource and thus eliminates distractor face processing. In a priming phase, participants performed speeded male/female judgements for famous face or gender symbol CITs that were flanked by famous distractor faces. Target CIT – distractor face pairings were either congruent with respect to the response category (i.e., both female or both male) or they were incongruent (i.e., male CIT / female distractor or vice versa). Interference effects in response times (RTs) from distractor faces on

CITs were assessed by contrasting incongruent with congruent conditions, and were separately analysed for face and non-face CITs. During a subsequent probe phase, participants made speeded fame judgements to previously seen (primed) or new (unprimed) famous faces. Probe faces were primed either by a distractor face, or by a face CIT presented during the priming phase, or they were unprimed (i.e., new). The experiments conducted in this research strand differed with respect to the CIT symbols used (gender symbols rotated in steps of 30° vs. upright gender symbols vs. more salient gender icons in Experiment 1, 2, and 3, respectively), the time interval between prime and probe (~20 minutes in Experiments 1 and 2, ~5 minutes in Experiment 3, respectively), and derived data type (response times and accuracies in Experiment 1 and 2, additional ERP correlates in Experiment 3, respectively). I will discuss the reasons for the respective changes in the general discussion section.

In all three experiments, interference costs in terms of slower responses for response-incongruent vs. response-congruent target CIT – distractor face pairings were observed. Critically, interference occurred only on symbol CITs, but not on face CITs, suggesting intact distractor face processing when the distractor face flanked a symbol (non-face) CIT, but impaired distractor face processing when it flanked an additional face CIT. In contrast, repetition priming in RTs was observed only from face CITs, but not from distractor faces (irrespective of CIT). However, relative to new faces, event-related brain potentials revealed a right occipito-temporal negativity between 400 and 600 ms for faces previously shown as distractor faces flanking symbol CITs that was absent for distractors flanking face CITs. In sum, these findings support recent notions of a face-specific attention resource with a capacity-limit of one face at a time.

2.6.2. Research strand 2

Strand 2 (Neumann & Schweinberger, 2008, submitted) introduced a modified immediate repetition paradigm (cf. Schweinberger et al., 2004). Analogous to Jenkins (2002), prime displays consisted of large face distractors that were presented in the centre of the screen. Superimposed on these faces, either letter string CITs (Experiment 4) or small face vs. building CITs (Experiments 5 and 6) were displayed. Perceptual Load was manipulated in accordance with Lavie's Perceptual Load Theory to CITs. Distractor faces remained task-irrelevant throughout the whole experiments, thus eliminating the confound of task-relevance and attention allocation in earlier studies (Eimer, 2000c; Martens et al., 2006; Trenner et al., 2004). In this research strand, repetition effects were assessed via modulations of repetition sensitive ERP components such as the N250r and the N400. Participants were not required to respond to probe faces in any of the experiments in order to rule out potential influences of motor responses on ERPs. Thus, no behavioural index of repetition priming in RTs or accuracies was obtained.

Experiment 4 investigated influences of attention to prime faces on immediate repetition effects in event-related potentials (ERPs). During prime presentation, participants attended to letter string CITs superimposed on distractor face images, and identified target letters “X” vs. “N” embedded in strings of either 6 different (high load) or 6 identical (low load) letters. Prime presentations were immediately followed by the probes. At probe presentation, distractor faces were either repeated, or a new famous face was presented, or an infrequent butterfly was presented, to which participants responded. The ERP data revealed repetition effects in terms of an N250r at occipito-temporal regions, suggesting priming of face identification processes, and in terms of an N400 at the vertex, suggesting semantic priming. Crucially, the magnitude of these effects was unaffected by perceptual load at prime presentation. This indicates that task-irrelevant face processing is remarkably preserved even in a demanding letter detection task, and supports recent notions of a face-specific attentional resource.

To test whether distractor face processing is effectively prevented by the presence of a second face in the display, face and building CITs were used in Experiments 5 and 6. The general procedure of Experiment 5 was similar to Experiment 4, with the difference that prime tasks now involved colour discrimination (low load) or age classification (high load) of face vs. building CITs. In Experiment 6, participants performed age classifications to famous and unfamiliar faces. For building CITs (Experiment 5), N250r repetition effects were found both under high and low load, replicating the main result from Experiment 4. However, for face CITs, N250r was reduced (Experiment 5) or even eliminated (Experiment 6) under high load. These findings extend the ERP evidence from Experiment 4 by revealing neural evidence for a face-specific attention resource with a capacity limit, allowing processing of only one face at a time.

3. Event-related potential correlates of repetition priming for ignored faces

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An attentional capacity limit was recently suggested for faces, such that only one face can be processed at a time. We measured interference and repetition priming caused by irrelevant distractor faces. Participants initially performed male/female judgments for central faces or symbols flanked by distractor faces. Interference (slower responses for gender-incongruent target-distractor pairs) occurred for central symbols but was absent for central faces. In subsequent fame judgements, previously presented distractor faces had no repetition priming effect on reaction-times. Relative to new faces, ERPs revealed a right occipitotemporal negativity ~400-600ms for faces previously shown as distractors flanking central symbols (but not distractors flanking faces). These findings support a face-specific attentional capacity limit, showing that ERP priming effects can reveal covert distractor processing.

Keywords: Attention, Priming, Event-related brain potentials, Face.

Introduction

Faces may capture attention to a larger degree than other visual stimuli, and undergo considerable processing even if irrelevant to an ongoing task or goal. It appears to be particularly difficult to ignore an incongruent but irrelevant face while processing a celebrity name [1], compared to ignoring an irrelevant object while processing an object name [2]. Category-specific distractor interference effects suggest the existence of a face-specific attentional capacity limit [3]. Moreover, when participants judged gender or nationality of a central face or non-face target (name, flag), a single incongruent distractor produced interference in all target-distractor combinations, except when a distractor face flanked a target face. These recent findings indicate that the attentional capacity for face processing may be limited, such that only one face can be processed at a time [4].

Research on repetition priming has indicated that prior exposure facilitates or alters the subsequent processing of a face at various levels of behavioural and neuronal processing [5,6]. It had originally been assumed that for priming to occur, the prime face needs to be overtly recognized [7]. By contrast, more recent research indicates that unattended faces may cause equivalent priming regardless of whether they are initially presented during a high or low attentional load task. Priming was also independent of whether participants explicitly remembered the initial presentation of the face [8]. Event-related brain potentials (ERPs) provide a high time resolution measure of neural processes affected by priming. ERPs may not only elucidate priming effects caused by subliminal (masked) prime stimuli [9,10], but are also sensitive to neural priming in the absence of behavioural facilitation [11]. ERP and neuroimaging research suggests that repetition priming of faces modulates activity in face-sensitive areas in bilateral or right fusiform gyrus and adjacent regions in ventral temporal cortex [12,13].

In the present study, we combine recent approaches to spatial attention and face-specific capacity limitations with face repetition priming. In particular, we address the questions of whether incongruent distractor faces interfere with the processing of central target symbols but not faces, and whether long-term repetition priming can be caused not only by faces originally presented as attended central targets, but also by faces originally presented as distractors flanking central symbols but not faces. While we expect ERP modulations by central priming similar to those reported previously

[12,14], we focus on whether ERPs reveal similar repetition modulations by faces originally presented as distractors flanking central target symbols but not faces.

Methods

Participants

Eighteen right-handed participants (mean age = 22.8 years, 12 female) contributed data to the main experiment. In two preceding behavioural studies, another 45 participants (study 1: N = 27, *M* = 22.8 years, 16 female; study 2: N = 18, *M* = 21.8 years, 13 female) were tested. All gave informed consent and the study was conducted in accordance with the Declaration of Helsinki.

Stimuli

Stimuli were b/w photographs of 216 famous and 48 unfamiliar faces (50% female), and common gender symbols (for examples cf. Fig.1).

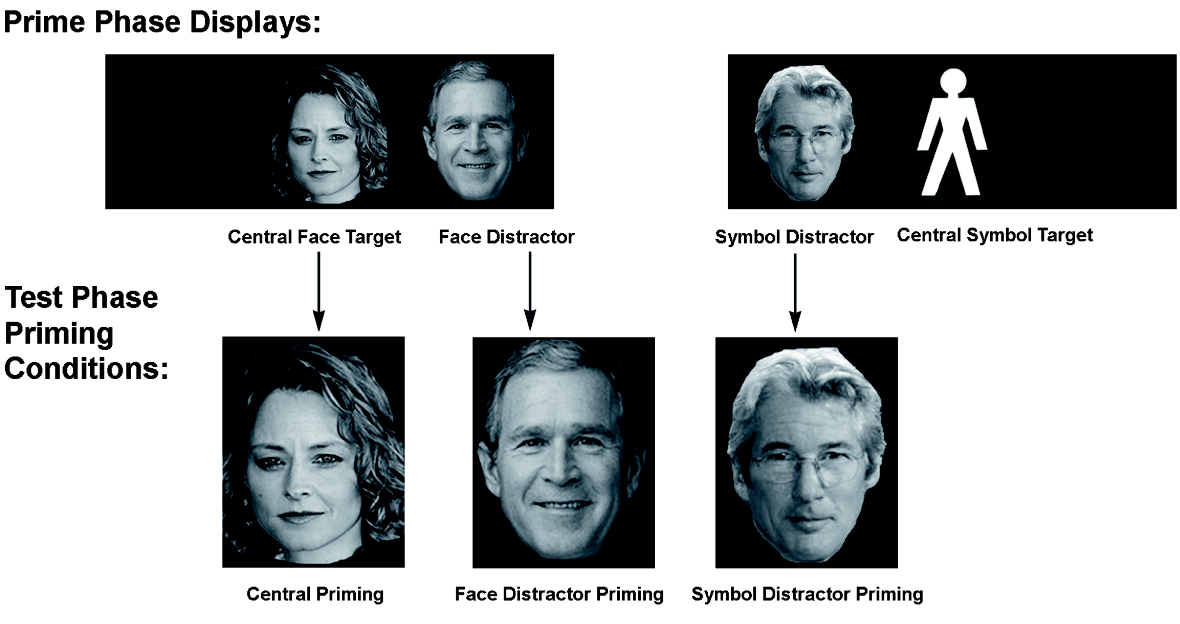

Fig. I Top: Prime phase stimuli. The left display shows a face target with a flanker face to the right. The right display shows a symbol target with a flanker face to the left. Bottom: Corresponding stimuli from the test phase, showing (a) central priming, (b) face distractor priming, and (c) symbol distractor priming. Note: Stimulus eccentricity is not to scale. See text for further details.

Prime displays consisted of a central target (either a face or a symbol) and a lateral flanker face. There were equal probabilities for flanker faces (a) to be shown to either side of the central item, and (b) to be of same or different gender as the central item. Stimulus size was 3.6º x 4.5º, and flanker eccentricity was 4.6º. Test stimuli were centrally presented faces (5.7º x 7.3º). All stimuli were presented at a viewing distance of ~90 cm, kept constant by a chin rest.

Procedure

Following short practice blocks (with different face sets), the experiment consisted of 3 blocks of *prime phases* (48 trials each) alternating with test phases (80 trials each). During each trial of the *prime phase*, a fixation cross was initially presented for 1000 ms, followed by a target-flanker image for 200 ms. Participants made speeded male/female gender judgments to the central target using the left and right index fingers, and were instructed to ignore the flanker face. Stimulus onset asynchrony (SOA) was 4000 ms.

In the *test phase blocks*, participants made speeded fame judgments for famous and unfamiliar faces. During each trial of the *test phase*, a fixation cross was initially presented for 1000 ms, followed by a test face for 1500 ms. SOA was 4000 ms. Famous faces in the test phase were either new (unprimed) or had been presented in the preceding prime phase block either as a central target (central priming), as a distractor flanking a face target (face distractor priming), or as a distractor flanking a symbol target (symbol distractor priming). Eighty trials were presented in randomized order in each of the three test phase blocks (3 x 16 trials for each of the 4 priming conditions, and 3 x 16 unfamiliar faces). The assignment of famous faces to priming conditions was completely counterbalanced across participants.

Initial behavioural studies were conducted to equate task difficulty of gender judgments between faces and symbols. These studies were generally analogous to the main experiment, but differed with respect to the number of face and symbol stimuli used, the nature of the gender symbols, and stimulus size and eccentricity.

Apparatus

We measured the electroencephalogram (EEG) using a 144 channel Biosemi™ Active II system. Electrode positions included 128 standard Biosemi sites plus 16 inferior temporal, occipitotemporal and occipital sites. EEG (DC to 100 Hz) was sampled at 256 Hz. Trials with incorrect behavioural response were removed. Bad trials were removed using automatic artefact detection [15]. Ocular contributions to the EEG were corrected using BESA™ 5.1. ERP epochs to test faces were quantified for

1400 ms (200 ms prestimulus baseline). ERPs were recalculated to average reference, and were digitally low-pass filtered at 20 Hz (zero phase shift).

Data Analysis

Repeated measure analyses of variance (ANOVAs) were calculated for analysing (a) congruency effects in the prime phase (with additional factors gender and central item type) and (b) repetition priming effects in the test phase.

For statistical analysis of ERPs, we pooled average ERPs within each of 14 regions of interest (ROIs). ROIs were frontal medial (FM), frontal right/left (FR, FL), central medial/right/left (CM, CR, CL), parietal medial/right/left (PM, PR, PL), temporal right/left (TR, TL), occipitotemporal right/left (OTR, OTL), and occipital medial (OM). For ERPs to faces in the test phase, we took mean amplitudes in time segments 140-170 ms (N170), 200-300 ms, 300-400 ms, and 400-600 ms. Initial ANOVAs were performed with repeated measures on ROI and priming condition. Significant interactions for any ROI were followed up by pair wise comparisons between the unprimed condition and each of the three priming conditions.

Behavioural Results

In the *prime phase* of the behavioural studies and the main experiment, gender judgements were faster for gender-congruent vs. incongruent flankers, as seen in a main effect of congruency, $F(1,26) = 9.2$, $p < .01$, $F(1,17) = 20.9$, $p < .001$, and $F(1,17) = 8.1$, $p < .01$, for study 1, study 2, and the main experiment, respectively. The congruency effect, however, was qualified by an interaction with central item type (face vs. symbol), $F(1,26) = 11.4$, $p < .01$, $F(1,17) = 3.6$, $p = .07$, and $F(1,17) = 4.0$, $p = .06$. This pattern reflected the fact that gender-incongruent distractor faces slowed processing of symbol targets, $F(1,26) = 12.5$, $p < .01$, $F(1,17) = 12.6$, $p < .01$, and $F(1,17) = 7.0$, $p < .05$, but did not affect processing of face targets, $F(1,26) = 1.5$, $p > .20$, $F(1,17) = 2.6$, $p > .10$, and $F(1,17) = 0.6$, $p > .20$ (cf. Fig. 2). Main effects of central item type reflected slower RTs for central symbol targets vs. central face targets in both behavioural studies only, $F(1,26) = 92.5$, $p < .001$ and $F(1,17) = 27.7$, $p < .001$. This main effect of central item type was absent in the main experiment, $F(1,17) = 1.9$, $p > .18$, showing that we successfully equated central item difficulty for faces vs. symbols. Response accuracy in the prime phase was near ceiling, M = 98.4% and 97.0% for face and symbol targets in the main experiment, respectively, and was therefore not analyzed further.

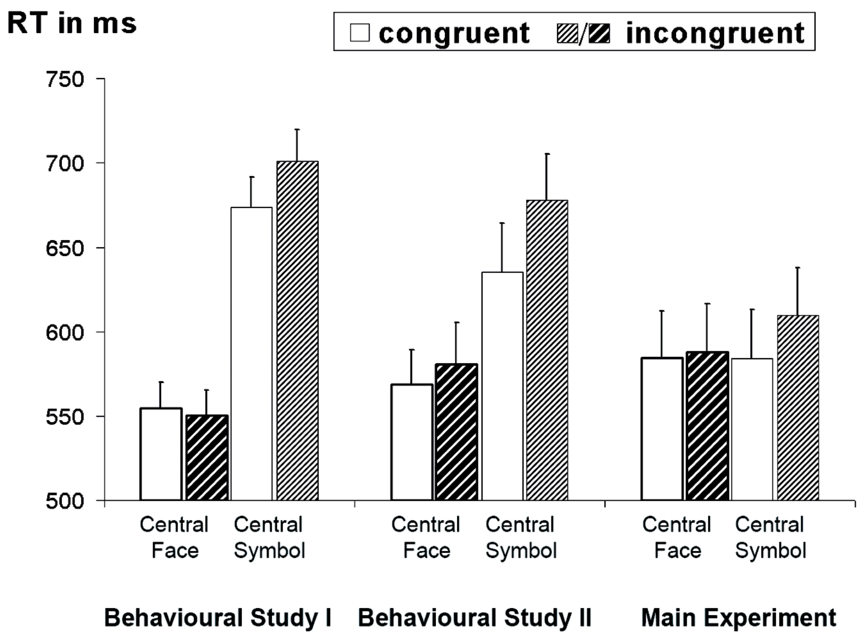

Fig. II Flanker congruency effects in response times for the two behavioural studies and the main experiment. Note that flanker face incongruency affects responses to central symbols but not those to central faces, demonstrating distractor processing for symbols targets only.

In the *test phase* of the main experiment, there was a main effect of priming in RTs to famous test faces, $F(3,51) = 19.1$, $p < .001$. RTs were faster for centrally primed vs. unprimed faces, $M = 678$ ms vs. 729 ms, respectively, $p < .01$. No RT priming was observed by either face distractors, $M = 739$ ms, or symbol distractors, $M = 732$ ms (both $p > .20$). Accuracies to famous test faces did not differ between conditions, $F(3,51) = 1.2$, $p > .20$, M = 87.6%, 86.2%, 84.8% and 84.9% for central priming, face distractor, symbol distractor, and unprimed conditions, respectively. Analogous patterns were seen in both behavioural studies.

ERP Results

The analysis of N170 amplitude did not reveal any effects of priming condition in interaction with ROI, $p > .20$. The same was true for the 200-300 ms segment and the 300-400 ms segment, *ps* > .20. The earliest effect of priming condition in interaction with ROI appeared in the 400-600 ms segment, $F(39,663) = 2.9$, $p < .01$. ERPs to centrally primed faces were more positive at medial parietal (PM), and more negative at occipitotemporal regions (OM, OTL, OTR, TL, and TR), all *ps* < .05. Of particular interest, the symbol distractor priming condition also caused significantly more negative ERPs at OTR, $p < .05$, with a similar but smaller effect at OTL, $p = .066$ (cf. Fig. 3). By contrast, the face distractor priming condition did not elicit a similar effect at occipitotemporal ROIs, *ps* > .18. No significant effects of face distractor priming were seen at any other ROI (for the topography of priming effects cf. Fig 4).

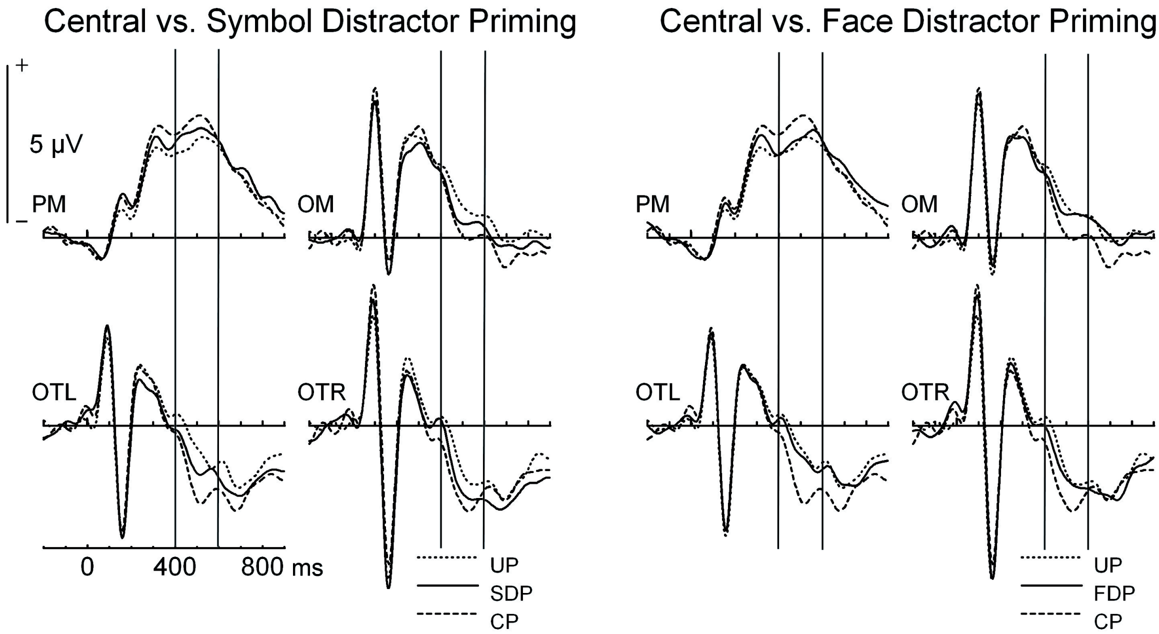

Fig. III Grand average event-related potentials (ERPs) for four regions of interest, across 18 observers. Left: The symbol distractor priming condition as compared with the unprimed and central priming conditions. Right: The face distractor priming condition as compared with the unprimed and central priming conditions. Note the ERP priming effect for symbol distractor priming, which was absent for face distractor priming. Vertical lines delimit the time segment 400-600 ms.

Peak latencies of N170 were determined at OTR as the most negative peak between 130 and 200 ms. N170 latencies did not differ between conditions, M = 157.6 ± 2.9, 156.1 ± 1.9, 156.4 ± 2.2, and 155.8 ± 2.4 ms for central priming, face distractor priming, symbol distractor priming, and unprimed conditions, respectively, $F(3,48) = 0.9$, $p > .20$.

Discussion

For gender classification of central symbol targets, we found a consistent pattern of interference (slowed RTs) from incongruent as compared to congruent distractor faces. Intriguingly, interference was completely absent for incongruent faces flanking a central face target. This replicates recent findings and adds further behavioural evidence for the idea of a face-specific capacity limit that allows the processing of only one face at a time [4].

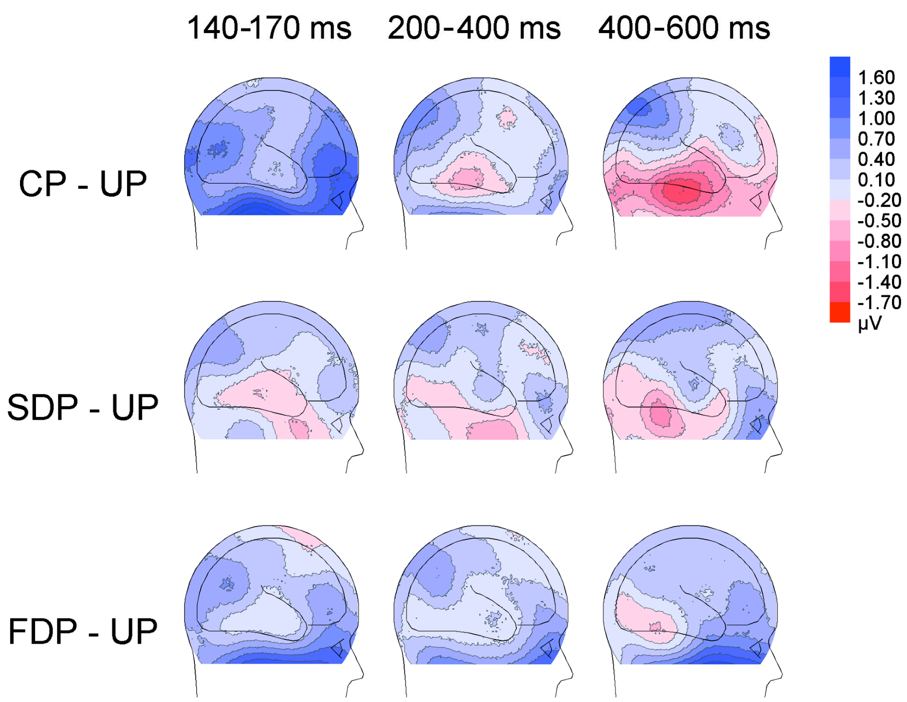

Fig. IV Voltage maps (spherical spline interpolation, 90º equidistant projection) for the ERP differences between each of three priming conditions minus the unprimed condition. CP = central priming; SDP = symbol distractor priming, FDP = face distractor priming. Note the right inferior temporal negativity (in red) ~400-600 ms for CP, and a smaller effect with similar topography for SDP. For FDP, the effect was reduced to insignificance.

Centrally attended target faces clearly elicited repetition priming in RTs during the test phase, in line with earlier findings [7,16]. In contrast, distractor faces that were shown outside the focus of spatial attention yielded no RT priming, irrespective of central item type (symbol vs. face). This may be an interesting contrast to a study by Jenkins et al. [8], who demonstrated RT priming from distractor faces. Unlike in the current experiment, however, the faces in that study were superimposed on the target stimuli, and thus were shown within the focus of spatial attention.

We observed clear ERP correlates of priming from central faces ~400-600 ms, which encompassed increased centroparietal positivity and increased occipitotemporal negativity to primed faces, similar to what was observed in previous studies [12,14]. Of particular interest, and despite the absence of RT priming effects, we observed a smaller but qualitatively similar priming effect during the same time segment from face distractors accompanying a central symbol. This underlines the suitability of ERPs to detect automatic priming effects even in the absence of RT priming [17]. One might speculate that the occipitotemporal maximum of this symbol distractor priming effect reflects a covert activation of facial identity representations in ventral temporal cortex [18]. Functional neuroimaging studies revealed face repetition effects in ventral temporal (fusiform) cortex which are typically seen bilaterally but tend to be larger in the right hemisphere [19-21], and the current topography of the symbol distractor priming effect is broadly in line with those findings.

In the context of current theories of attentional capacity limits for face processing, it is noteworthy that no significant RT and ERP priming effects were found for faces presented as distractors when these were flanking a central face during the prime phase.

Conclusion

In addition to behavioural interference effects the present ERP findings may provide the first electrophysiological evidence for current notions of a face-specific attentional capacity limit. Our findings also underline the ability of ERPs to reveal neural priming effects that demonstrate covert distractor processing in the absence of behavioural priming.

Acknowledgements

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4. N250r and N400 ERP correlates of immediate famous face repetition are independent of perceptual load

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It is a matter of considerable debate whether attention to initial stimulus presentations is required for repetition-related neural modulations to occur. Recently, it has been assumed that faces are particularly hard to ignore, and can capture attention in a reflexive manner. In line with this idea, electrophysiological evidence for long-term repetition effects of unattended famous faces has been reported. The present study investigated influences of attention to prime faces on short-term repetition effects in event-related potentials (ERPs). We manipulated attention to short (200 ms) prime presentations (S1) of task-irrelevant famous faces according to Lavie's Perceptual Load Theory. Participants attended to letter strings superimposed on face images, and identified target letters "X" vs. "N" embedded in strings of either 6 different (high load) or 6 identical (low load) letters. Letter identification was followed by probe presentations (S2), which were either repetitions of S1 faces, new famous faces, or infrequent butterflies, to which participants responded. Our ERP data revealed repetition effects in terms of an N250r at occipito-temporal regions, suggesting priming of face identification processes, and in terms of an N400 at the vertex, suggesting semantic priming. Crucially, the magnitude of these effects was unaffected by perceptual load at S1 presentation. This indicates that task-irrelevant face processing is remarkably preserved even in a demanding letter detection task, supporting recent notions of face-specific attentional resources.

Keywords: repetition; face; attention; ERP; N250r; N400

Introduction

Presenting stimuli repeatedly leads to alterations in subsequent processing of the same stimuli, an effect often referred to as repetition priming. Repetition modulations can not only be observed in behaviour (e.g., faster reaction times and improved accuracies for repeated as compared to new stimuli), but can also be established using electrophysiological or neuroimaging methods (Grill-Spector, Henson, & Martin 2006). One interesting and controversially discussed question is the degree to which prime stimuli can be processed, and can cause subsequent repetition modulations, even when presented in the absence of selective attention. A considerable part of this discussion has focussed on the processing of face stimuli, which may attract, or “capture”, attention to a greater extent than other stimuli (Bindemann et al. 2007; Langton et al. 2008; Theeuwes & Van der Stigchel 2006), but see (Jackson & Raymond 2006). Specifically, faces were sometimes found to produce repetition modulations even when not attended to at first presentation (e.g., Jenkins, Burton, & Ellis 2002). It has also been recently suggested that faces are processed in a face-specific attentional resource (Bindemann, Burton, & Jenkins 2005; Jenkins, Lavie, & Driver 2003).

The question of whether attention to a face might or might not be a prerequisite for implicit recognition to occur has been explored by studies using functional magnetic resonance imaging (fMRI). Stimulus repetition typically causes reduced Blood Oxygen Level Dependent (BOLD) responses to second as compared to first presentations of the image, the “repetition suppression effect”, although enhanced responses to repeated stimuli have also been reported (for a review, cf. Henson 2003; Henson, Shallice, & Dolan 2000). With respect to the role of attention to prime faces, results were inconsistent. Henson et al. (Henson & Mouchlianitis 2007) found repetition suppression for repeated faces (S2) only if participants attended to both first (S1) and second (S2) stimulus presentations. By contrast, Bentley et al. reported repetition decreases in occipito-temporal cortex irrespective of whether S1 faces were presented at attended or ignored positions (Bentley et al. 2003).

One reason why studies might differ in their results regarding the role of attention to prime faces on repetition effects may be the difference between studies in the experimental manipulation of attention. Specifically, the perceptual load of the tasks used in the different studies may account for the differences in the obtained results (also cf. Henson & Mouchlianitis 2007). According to the influential Perceptual Load Theory (Lavie 1995; Lavie 2005; Lavie & Fox 2000), visual perception is capacity-limited. Within this capacity, though, task-irrelevant distractor processing occurs mandatorily unless all available capacity is consumed by the task-relevant target(s). Thus, while processing of task-irrelevant distractor items is inevitable when capacity is available (i.e., low perceptual load), distractor processing should be abolished when capacity is fully recruited by target processing (i.e., high perceptual load).

Following this rationale, repetition priming by distractor faces presented in high perceptual load conditions should be abolished or at least strongly reduced. In a recent study (Jenkins, Burton, & Ellis 2002), Jenkins et al. presented prime displays consisting of letter strings superimposed on task-irrelevant famous faces. Perceptual load in an unrelated letter search task was manipulated, and probe displays consisted of previously presented distractor faces or new famous faces. Crucially, distractor faces caused repetition priming effects (faster responses to repeated in comparison to new famous faces) of identical magnitude in both high and low perceptual load conditions. Accordingly, distractor faces were implicitly processed, irrespective of the amount of capacity recruited by the unrelated letter search task. Interestingly, however, while distractor face processing was sufficient to allow for repetition priming, it did not support explicit recognition. Rather, explicit face memory was dramatically reduced when faces had been presented as distractors under high as compared to low load conditions, consistent with the predictions from Perceptual Load Theory.

Event-related potentials (ERPs) provide a useful tool to investigate timing of cognitive processes underlying repetition effects (e.g., priming). Studies that investigated ERP repetition effects for faces frequently focussed on three ERP components as described below.

First, the N170 is a prominent response over occipito-temporal areas, which is prominent for faces but is much smaller for most other visual stimuli (Bentin et al. 1996; Bentin et al. 2007; Rossion & Jacques 2008; Thierry et al. 2007). The N170 is often thought to reflect relatively early processes in face perception related to the detection of a facial pattern, to the structural encoding of faces, or both (Eimer 2000b; Engst, Martin-Loeches, & Sommer 2006). Evidence for the sensitivity of the N170 to face repetitions is somewhat controversial: While face repetitions did not appear to affect N170 amplitude in a majority of studies (Eimer 2000b; Engst, Martin-

Loeches, & Sommer 2006; Schweinberger et al. 2002b), other recent studies reported a small effect of repetition on N170 amplitude (Heisz, Watter, & Shedden 2006; Itier & Taylor 2002; Itier & Taylor 2004; Jemel et al. 2005).

Second, the N250r is an electrophysiological correlate more consistently found for immediate face repetitions (Begleiter, Porjesz, & Wang 1995; Engst, Martin-Loeches, & Sommer 2006; Henson 2003; Pfütze, Sommer, & Schweinberger 2002; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann 2002b; Schweinberger, Huddy, & Burton 2004; Schweinberger, Pfütze, & Sommer 1995). This component refers to a relatively more negative ERP for repeated as compared to unrepeated faces, a difference which peaks between about 230 and 330 ms over right inferior temporal regions. This component is consistently found to be larger for familiar than unfamiliar face repetitions (Begleiter, Porjesz, & Wang 1995; Herzmann et al. 2004; Pfütze, Sommer, & Schweinberger 2002; Schweinberger, Pfütze, & Sommer 1995) and is thought to reflect a transient activation of facial representation for face recognition (Itier & Taylor 2004).

Third, repetitions of faces have also been shown to modulate N400-like components (Bentin & McCarthy 1994; Cooper et al. 2007; Schweinberger et al. 2002a). The N400 is a negative ERP at centro-parietal regions, and may be the best-known ERP that is sensitive to priming. This relatively late-latency ERP is thought to be related to the semantic integration of the current stimulus into the preceding context. Consistent with this idea, N400 for faces was found to be larger for familiar as compared to unfamiliar faces (Barrett, Rugg, & Perrett 1988; Eimer 2000a; Schweinberger, Pfütze, & Sommer 1995).

So far, only few EEG studies dealt with the influence of attention to S1 faces on ERP repetition effects. In one study, Eimer et al. (Eimer 2000b) presented familiar faces, unfamiliar faces, and houses, while a 5-item alphanumeric string was centrally presented superimposed on faces and houses. In the “attended” condition, participants had to detect immediate face or house repetitions, whereas in the “unattended” condition, they had to detect a single digit in the 5-item string. In this study, N400 familiarity modulations were found for attended but not for unattended faces. Two recent studies (Martens et al. 2006; Trenner et al. 2004) compared immediate repetition effects for direct vs. indirect task conditions. In both studies, the authors found larger N250r amplitudes in a direct matching task (that is, first and second presentation were both attended and task relevant) as compared to an indirect priming task (only second presentations were task-relevant) (Martens, Schweinberger, Kiefer, & Burton 2006). The authors concluded that the N250r does not reflect completely automatic aspects of face processing, but is modulated by either attention or task relevance.

All three studies compared tasks in which faces were task-relevant (and therefore supposed to be attended) with tasks in which faces were task-irrelevant (and therefore thought to be unattended). According to the Perceptual Load Theory, however, the latter assumption is not necessarily true. Even though they were task-irrelevant, faces might have been attended to in both the “indirect task” and the “detect digits” conditions, provided that attentional capacity was not fully consumed by the primary task. This has not been controlled for in either study. Moreover, the confound of task-relevance and attention makes the results difficult to interpret, such that the contribution of attention remains unclear.

To our knowledge, no study so far directly investigated effects of perceptual load manipulations to prime stimuli on repetition-sensitive ERP components. Consequently, this was the main target of the current experiment. An additional benefit of manipulating attention according to Perceptual Load Theory is that it allowed us to avoid a confound of attentional effects with task-relevance. We manipulated attention in an unrelated task, while repetition priming was measured from task-irrelevant distractors only. We used an immediate repetition paradigm (Schweinberger, Huddy, & Burton 2004) to establish the role of attention for ERP correlates of face repetitions by manipulating perceptual load to S1 faces. Participants were successively presented with pairs of images (cf. Figure 1). S1 displays comprised of letter strings, superimposed on famous faces, and were presented for 200 ms. Participants had to identify a target letter (“X” vs. “N”) embedded either in a string of six identical letters (low load, e.g. “NNNNNN”) or in a string of 6 different letters (high load, e.g. “HKNWMZ”) (cf. Jenkins, Lavie, & Driver 2005, experiment 2). Participants were explicitly instructed that S1 faces were task-irrelevant and should be ignored. S1 displays were followed by S2 displays (stimulus onset asynchrony; SOA = 2000 ms) consisting of either a repetition of the distractor face, a new famous face, or an infrequent butterfly. Participants had to respond by button press to butterflies only. Speed and accuracy was emphasised for both the letter detection task and the butterfly detection task. The butterfly detection task was included to ensure that participants attended to S2 stimuli, while enabling us to investigate face repetition effects uncontaminated by neural activity related to motor responses.

It has been shown that effects of perceptual load on attentional selection can arise during initial stages of visuocortical processing (Handy, Soltani, & Mangun 2001). If high perceptual load can prevent distractor face processing, as predicted by the Perceptual Load Theory, then we expect ERP repetition modulations to appear under low but not under high perceptual load. Behavioural evidence, though, suggested that processing of face distractors can occur to a certain extent even in high load conditions (Jenkins, Burton, & Ellis 2002).

Assuming that this would be the case, we reasoned that an analysis of ERP repetition effects caused by task-irrelevant S1 faces presented under either low or high perceptual load would allow a relatively detailed insight into the processing of faces in the absence of selective attention. Specifically, the N170, N250r, and N400 have been related to successive stages related to structural encoding, face identification, and semantic processing, respectively. Based on previous studies of ERP face repetition effects, which yielded inconclusive results, we did not have a specific prediction with respect to the N170. In the low load condition, we expected both occipito-temporal N250r effects and centro-parietal N400 effects of face repetitions similar to those described in the literature (Barrett, Rugg, & Perrett 1988; Begleiter, Porjesz, & Wang 1995; Eimer 2000a; Engst, Martin-Loeches, & Sommer 2006; Henson 2003; Pfütze, Sommer, & Schweinberger 2002; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann 2002b; Schweinberger, Huddy, & Burton 2004; Schweinberger, Pfütze, & Sommer 1995). Crucially, we determined whether or not S1 faces presented under high load conditions would be able to elicit similar face repetition effects in these ERP components.

Results

Behaviour

Responses were scored as correct if the appropriate response was given within 1800 ms to S1 letter strings, and within 2000 ms to S2 butterflies, respectively. To assess whether load in S1 displays was manipulated successfully, we compared response times (RTs) and accuracies to primes for high and low perceptual load conditions. Responses were faster in low load as compared to high load trials (M = 572 ms vs. M = 817 ms in low load and high load conditions, respectively; $t[19] = 9.64$, p <

.001). Participants were more accurate in low load as compared to high load trials (M = .95 vs. M = .72 for low load and high load conditions, respectively; t[19] = 13.94, p < .001).

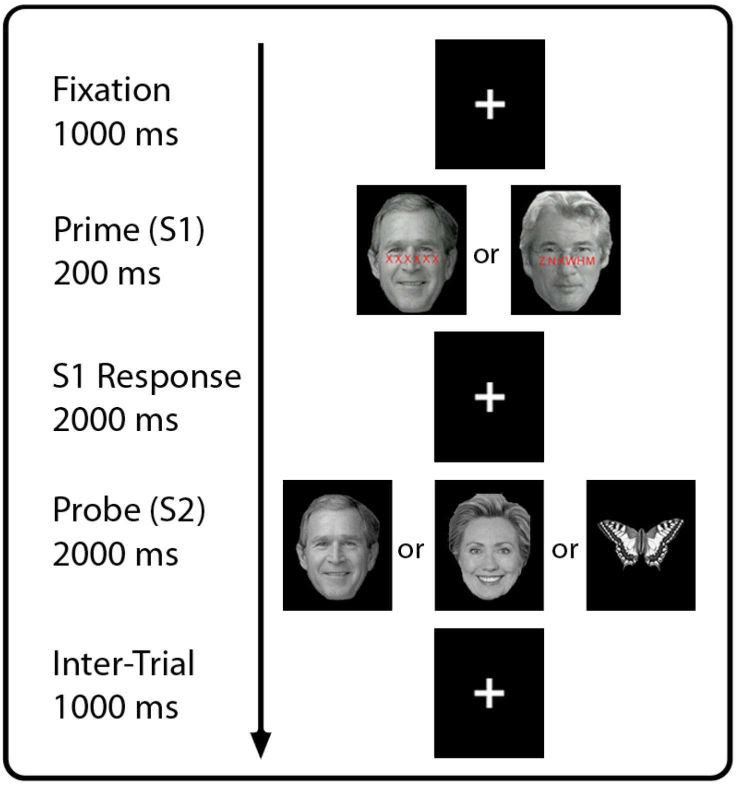

Fig. 1 General trial procedure. Primes (S1) consisted of letter strings (originally in red colour), presented superimposed on famous faces. “N” or “X” responses to letters were required. Left image: Low Load (6 target “X”), right image: High Load (1 target “N” among 5 non-target letters “H”, “K”, “W”, “M”, and “Z”). Probes (S2) were repetitions of previously presented distractor face (left image), new famous faces (middle), or butterflies (right). Participants responded to butterflies only. Note: Stimulus size is not to scale.

S2 butterflies were detected with near-ceiling accuracy (probability for correct butterfly detection > .99). No significant difference (p > .20) was found for high and low load conditions in accuracies, that is, the load status of the previously presented S1 task had no effect on S2 butterfly detection accuracy. A small load effect was found in RTs to S2 butterflies, though. Detection was slightly faster when butterflies were preceded by a low load S1 display as compared to those preceded by a high load S1 display (M = 497 ms vs. M = 517 ms for low and high load, respectively; t[19] = 2.82, p < .05).

Event-related potentials

For statistical analyses, we pooled signals of all 144 recorded electrodes within 14 regions of interest (ROI), which were selected based on prior priming studies (cf. Neumann et al. 2007; Wiese, Schweinberger, & Neumann 2008). For ERPs elicited by S2 faces, we calculated mean amplitudes in time segments 80-120 ms (occipital P1), 140-180 ms (occipito-temporal N170), 180-220 ms (posterior P2), 220-300 ms / 300-400 ms (early and late part of the occipito-temporal N250r), and 400-500 / 500-600 ms (early and late part of the centro-parietal N400).

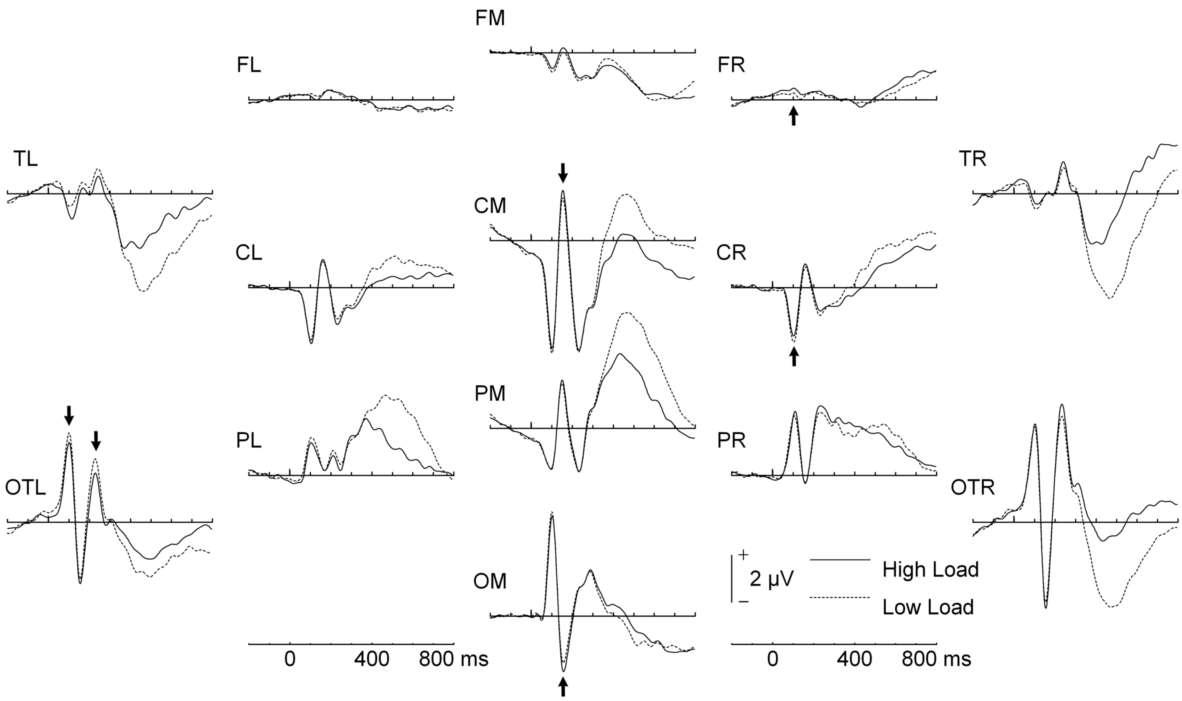

Fig. 2 Effects of load manipulation on ERPs to S1 stimuli. Note the early load effects at OTL, and the large modulations by task load onsetting at ~300 ms. FM: frontal medial, FR: frontal right, FL: frontal left, CM: central medial CR: central right, CL: central left, TR: temporal right, TL: temporal left, PM: parietal medial, PR: parietal right, PL: parietal left, OTR: occipito-temporal right, OTL: occipito-temporal left, OM: occipital medial. Arrows indicate significant effects of Load before 300 ms.

ERPs to S1 displays were evaluated using the same time segments. Note that recalculation to average reference sets mean activity across all electrodes to zero. Therefore, all reported effects including the experimental factors Load or Repetition are in interaction with ROI.

ERPs to S1 prime displays

Figure 2 illustrates the effects of the load manipulation on ERPs elicited by S1 displays. Visual inspection indicates prominent and wide-spread load effects in late ERP segments from approximately 300 ms onward, as well as smaller and more local effects in earlier components. To quantify these observations, an initial ANOVA with repeated measures on ROI and Load was conducted. ROI*Load interactions were significant in the 80-120 ms interval ($F[13,247] = 2.79$, $p < .05$), the 140-180 ms interval ($F[13,247] = 2.78$, $p < .05$), the 180-220 ms interval ($F[13,247] = 2.44$, $p < .05$), the 300-400 ms interval ($F[13,247] = 5.82$, $p < .001$), the 400-500 ms interval ($F[13,247] = 24.16$, $p < .001$), and the 500-600 ms interval ($F[13,247] = 22.08$, $p < .001$). Follow-up analyses for the P1, N170, and P2 interval were performed for each region separately. In the 80-120 ms time segment, ERPs to low load trials were more positive at OTL ($t[19] = 2.34$, $p < .05$), and more negative at FR and CR ($t[19] = 2.13$ and $t[19] = 2.40$, respectively, both $p < .05$) regions. In the 140-180 ms time segment, amplitudes were smaller for low as compared to high load trials at CM ($t[19] = 2.67$, $p < .05$) and OM ($t[19] = 6.36$, $p < .001$). In the 180-220 ms time interval, a larger positivity for low as compared to high load trials was again found at OTL ($t[19] = 2.81$, $p < .05$).

In time segments between 300 ms and 600 ms, amplitudes were strongly modulated by Load over central, parietal, and bilateral occipito-temporal and temporal regions (though more pronounced over the right hemisphere), with more positive going ERPs for low vs. high load trials at central and parietal ROI, and more negative going ERPs for low vs. high load trials at temporal and occipito-temporal ROIs (cf. Figure 2)[1].

ERPs to S2 stimuli:

The initial ANOVA with repeated measures on ROI, Load, and Repetition revealed no significant main effects or interactions involving the factors Repetition or Load for the P1, the N170[2], and the posterior P2.

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[1] Between 400 and 600 ms, these effects were highly significant in all the ROIs mentioned in the text. For the sake of brevity, and because S1-elicited ERPs were not at the focus of the present study, we refrain from reporting detailed statistics for these load effects.

[2] Please note that repetition effects for the N170 were not significant at OTL ($F[1,19] < 1$) and OTR ($F[1,19] < 1$) even when tested separately.

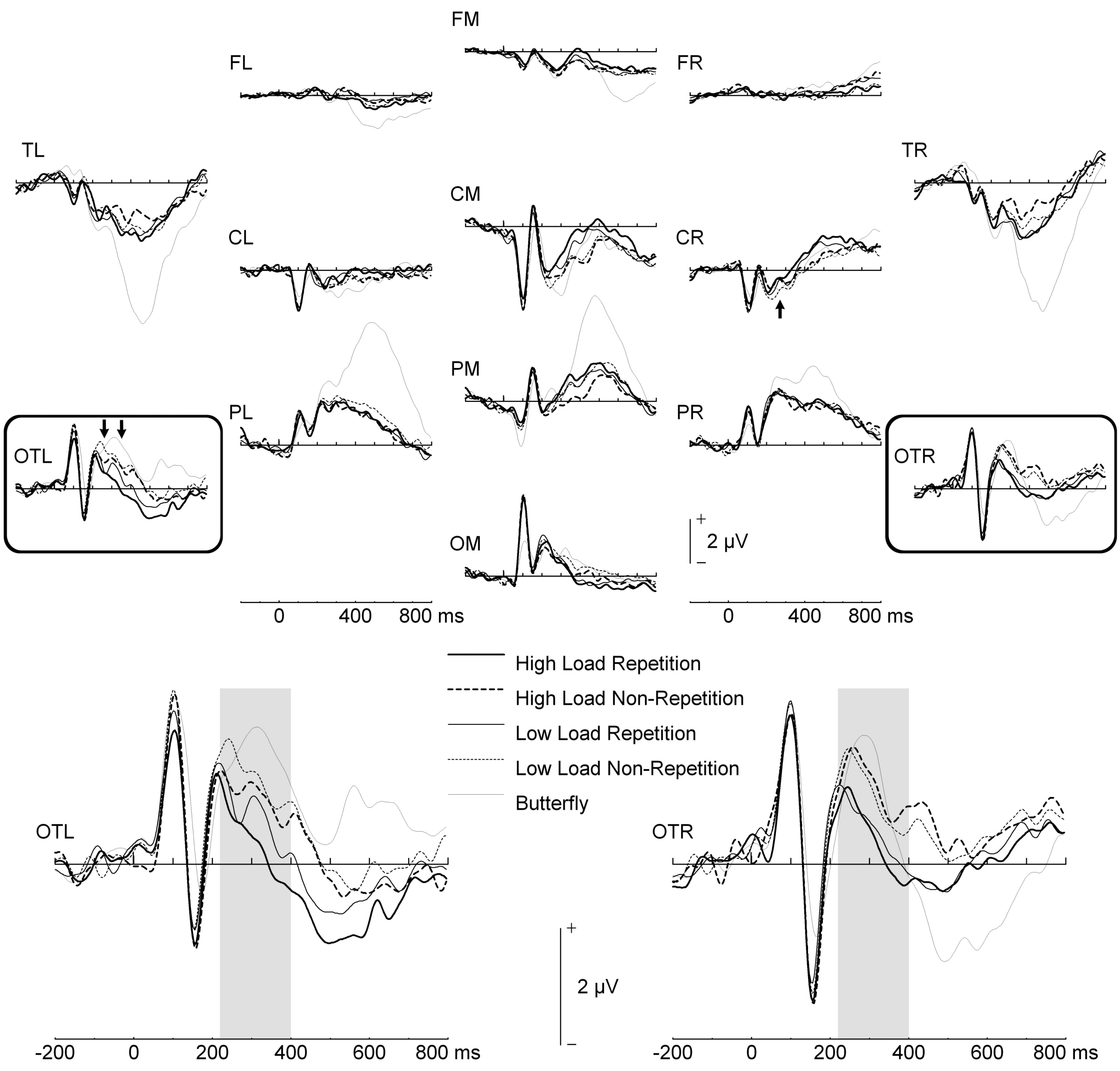

Fig. 3 ERPs to S2 stimuli for all Load and Repetition conditions. ROIs as specified in Figure 2. Bottom: Enlarged waveforms at bilateral occipito-temporal regions OTR and OTL. Arrows at CR and OTL indicate significant effects of Load (220-300 ms at CL, 220-400 at OTL). The grey shaded interval at enlarged OTR and OTL regions encompasses early and late N250r time segments 220-300 and 300-400 ms.

The earliest experiment effect in the global ANOVA was a Repetition*ROI modulation in the 220-300 ms time segment ($F[13,247] = 3.59$, $p < .01$). Single ROI analyses yielded significant repetition effects at OTR ($F[1,19] = 6.05$, $p < .05$) and OTL ($F[1,19] = 6.02$, $p < .05$) regions (cf. Figure 4). Repeated faces caused more negative (or less positive) going ERPs than unrepeated faces at these locations. As in previous studies, a similar but polarity-reversed effect was present over midline regions FM ($F[1,19] = 4.77$, $p < .05$), CM ($F[1,19] = 5.59$, $p < .05$), and PM ($F[1,19] = 7.16$, $p < .05$).

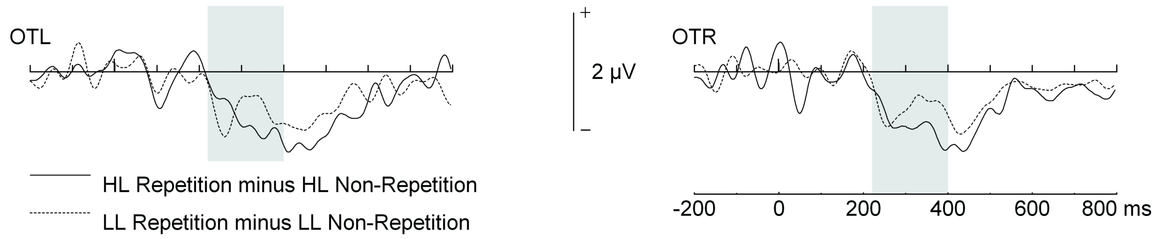

Fig. 4 Repetition effects (difference curves) at right and left occipito-temporal sites for High and Low Load conditions. Solid lines indicate repetition effects from distractor faces presented under high load; dotted lines indicate repetition effects under low load. The grey shaded interval encompasses early and late N250r time segments 220-300 and 300-400 ms. Note that repetition effects starting at ~220 ms emerged for both load conditions, with no evidence for reduced effects under high load.

Effects of load were also present in this time interval. Low load caused more negative ERPs ($F[1,19] = 5.56$, $p < .05$) at CR, and more positive ERPs ($F[1,19] = 5.68$, $p < .05$) at OTL. Importantly, no interaction involving Load and Repetition was found in either region ($F[1,19] = 0.91$, $p > .20$, and $F[1,19] = 2.34$, $p > .10$, for OTL and CR, respectively).

A similar pattern of results was found in the 300-400 ms time segment. Again, the initial global ANOVA revealed a significant Repetition*ROI interaction ($F[13,247] = 6.63$, $p < .001$) only. Separate ANOVAs for single regions revealed significant repetition effects at bilateral occipito-temporal (OTR, OTL), temporal (TR, TL) and midline regions FM, CM, and PM. ERPs to repeated faces were more negative (less positive) going at OTR ($F[1,19] = 10.56$, $p < .01$), OTL ($F[1,19] = 9.33$, $p < .01$), TR ($F[1,19] = 5.14$, $p < .05$), and TL ($F[1,19] = 5.25$, $p < .05$), and were less negative (more positive) going at FM ($F[1,19] = 6.82$, $p < .05$), CM ($F[1,19] = 11.17$, $p < .01$), and PM ($F[1,19] = 7.68$, $p < .05$) regions. The effect of load at OTL observed in the 220-300 ms time segment was still present in the 300-400 ms time segment ($F[1,19] = 4.80$, $p < .05$) but again, no interaction with repetition was observed ($F[1,19] = 1.18$, $p > .20$).

Initial analyses in time segment 400-500 ms again yielded repetition effects ($F[13,247] = 9.70$, $p < .001$), but no effect of Load ($p > .20$), and no interaction involving Repetition and Load ($p > .10$). Figure 3 shows that repetition effects were prominent at CM ($F[1,19] = 23.32$, $p < .001$), but were also significant at CR ($F[1,19]=16.11$, $p <.01$), OTR ($F[1,19] = 14.08$, $p < .01$), OTL ($F[1,19] = 13.28$, $p < .01$), OM ($F[1,19] = 12.44$, $p < .01$), CL ($F[1,19] = 10.89$, $p < .01$), FM ($F[1,19] = 10.02$, $p < .01$), TR ($F[1,19] = 6.81$, $p < .05$), TL ($F[1,19] = 5.53$, $p < .05$), with a trend at PM ($F[1,19] = 4.10$, $p = .057$).

Effects of repetition were reduced to a trend in the 500-600 ms segment (F[13,247] = 1.99, p = .088). Similarly, there was no effect of Load during that time segment (F[1,19] = 1.19, p > .20), and no interaction involving Load and Repetition (F[1,19] = 1.47, p > .20).

Discussion

In the current experiment, we investigated ERP correlates of repetition priming caused by task-irrelevant distractor faces presented under conditions of high or low perceptual load. According to the Perceptual Load Theory, processing of distractors should occur in low, but not in high perceptual load conditions, a pattern which has been previously demonstrated for a range of distractor stimuli including moving dot patterns (Rees, Frith, & Lavie 1997; Wiese, Schweinberger, & Neumann 2008), lexical stimuli (Lavie 1995), or scenes (Yi et al. 2004). By contrast, the present ERP results provide clear evidence for distractor face processing irrespective of perceptual load in an unrelated letter search task. Strikingly, we found priming effects in repetition-sensitive ERP components, in particular N250r and N400, even when processing of first face presentations should have been prevented or at least diminished by high perceptual load.

Immediate repetition of famous faces had no effect on the N170 component in our experiment. This pattern that is in line with numerous previous studies (Bentin & Deouell 2000; Cooper, Harvey, Lavidor, & Schweinberger 2007; Eimer 2000b; Engst, Martin-Loeches, & Sommer 2006; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann 2002b), although it should be acknowledged that face repetition effects on early ERPs before 200 ms were reported to occur in specific conditions of stimulus presentation (Itier & Taylor 2004; Jemel, Pisani, Rousselle, Crommelinck, & Bruyer 2005; Martens, Schweinberger, Kiefer, & Burton 2006). In contrast to many previous studies, it should be noted that we presented all S2 faces at a smaller size than S1 faces, such that there were no exact repetitions of the same stimulus.

In line with earlier studies (Schweinberger, Pickering, Burton, & Kaufmann 2002a; Schweinberger, Huddy, & Burton 2004; Schweinberger, Pfütze, & Sommer 1995; Trenner, Schweinberger, Jentzsch, & Sommer 2004), we observed an occipito-temporal N250r ERP modulation for immediately repeated vs. unrepeated famous faces starting around 220 ms. Of particular importance, this N250r effect was not only present in low but also in high perceptual load trials. Moreover, the effects for both load conditions were of comparable size (cf. Fig. 3 and Fig. 4).This finding sheds more light on the aforementioned interpretation of two studies, which concluded that the N250r is modulated by either task-relevance or attention (Martens, Schweinberger, Kiefer, & Burton 2006; Trenner, Schweinberger, Jentzsch, & Sommer 2004). Specifically, the larger N250r for a “direct” matching condition as compared to an “indirect” familiarity task (Martens, Schweinberger, Kiefer, & Burton 2006; Trenner, Schweinberger, Jentzsch, & Sommer 2004) does not appear to reflect differences in attention to prime faces. If this were the case, and if attention was the critical factor for N250r modulations, we should have observed similar effects in the present study that directly manipulated attention to prime stimuli while keeping task-relevance constant. The N250r has been interpreted to reflect the transient activation of stored facial representations, or “face recognition units” (Bindemann et al. 2008; Martin-Loeches, Sommer, & Hinojosa 2005). Accordingly, our N250r results suggest that distractor faces presented under high perceptual load were able to activate this “identity route” of face processing to a similar extent as observed under low perceptual load. While striking, this result is in line with the idea that the recognition of familiar faces is “mandatory” in many circumstances (Bindemann, Burton, Leuthold, & Schweinberger 2008; Ellis, Young, & Flude 1990).

In addition to N250r priming effects, we found significant repetition effects between 400 and 500ms at central electrodes, and a similar trend at more parietal electrodes. This effect corresponds to an N400 modulation as previously reported for the repetition of familiar faces (Jemel et al. 2003), likely reflecting the processing of semantic information in person recognition. Similar to the N250r, this N400 repetition effect was largely unaffected by attentional load. At midline central electrodes (at which the N400 effect was maximal), there was no evidence for a reduction of the effect in the high load condition. This suggests that the processing of task-irrelevant distractor faces extended to a remarkably deep level of semantic information even under conditions of high perceptual load.

Our finding of distractor face processing under high perceptual load conditions not only supports results of a recent study (Jenkins, Burton, & Ellis 2002), but also sheds further light on the underlying mechanisms. Jenkins et al. (Jenkins, Burton, & Ellis 2002) reported repetition priming in RTs from faces presented as distractors in a condition of high load. Processing of distractor faces in that study seemed to be relatively deep, in that RT priming survived an image change between prime and probe presentation. While this would seem to suggest that distractor faces were able to activate view-independent face representations, our results further suggest that the present distractor faces were able to activate semantic representations of the famous faces presented as S1 stimuli. Note that this does not necessarily mean that the present distractor face processing would have supported explicit storage and recognition over longer time periods. In fact, even though semantic activation by unattended or masked stimuli has been observed in a variety of conditions, this activation is often found to be very short-lasting when compared to attended or unmasked stimuli (Kiefer & Spitzer 2000).

Although one could argue that the high load task simply may not have been demanding enough to sufficiently prevent face distractor processing, our behavioural results suggest that this explanation is unlikely. Participants were much slower and much more error-prone in the high load as compared to the low load condition. At the same time, performance was clearly above chance level in all experimental conditions, suggesting that participants were highly focussed on the letter strings. In view of the large performance differences between the two load conditions, the complete absence of differences in the N250r effect elicited by distractor face primes is particularly remarkable.

ERPs to prime displays revealed a smaller P300-like peak (sometimes referred to as late positive component, LPC) at parietal regions in the high vs. low load condition, cf. Figure 2). This finding is consistent with a large number of previous reports that P300 amplitude is reduced for increased difficulty of stimulus evaluation (e.g. Mecklinger, Kramer, & Strayer 1992; Verleger 1988). In addition to these prominent late effects of perceptual load, we found slightly decreased P1 and P2 amplitudes in the high load condition at left occipito-temporal sites. ERP correlates of orthographic processing of letter strings and words have been described within the initial 250 ms (Grossi & Coch 2005; Proverbio, Vecchi, & Zani 2004), and left ventral occipito-temporal brain regions are thought to reflect various aspects of orthographic processing (Allison et al. 1994; McCandliss, Cohen, & Dehaene 2003). We therefore speculate that the above effects in the P1 and P2 reflect systematic differences in the letter strings used in our low vs. high load conditions. As a limitation, it needs to be noted that since our S1 displays consisted of letter strings superimposed on faces, it is difficult to unequivocally relate the ERP response to S1 displays to either of these stimuli.

Our findings suggest that load manipulation in an unrelated task using non-face stimuli (letters) does not prevent distractor faces from being processed. This idea is in line with a number of recent articles that propose the existence of a separate face-selective attentional system. Evidence for such a system has been provided by findings that non-face targets do not interfere with the processing of distractor faces, whereas even a single target face virtually abolishes distractor face processing. This led to the further suggestion that the putative face-selective attentional system is capacity-limited to the processing of only one face at a time (Bindemann, Jenkins, & Burton 2007; Bindemann, Burton, & Jenkins 2005; Neumann, Schweinberger, Wiese, & Burton 2007). If these assumptions are correct, distractor face processing should be effectively prevented by using an unrelated task which involves target faces, rather than target letters during prime presentations. A related study (Morgan et al. 2008) investigated the role of working memory load on face sensitive ERP components (N170, N250r, and the memory-related P3b). Interestingly, the authors reported modulations of all these components by working memory load in encoding and recollection phases. Most relevantly, both N170 and N250r amplitudes to a test face were found to be reduced when encoding was under high working memory load (e.g., 2, 3, or 4 faces presented simultaneously instead of only one single face). These findings may be in line with notions that processing of more than one face at a time is hard to accomplish, and suggest that repetition sensitive ERP components depend on working memory load. This is a potentially interesting contrast to the present results, which suggest that repetition sensitive ERP components do not depend on perceptual load, at least in a situation in which distractor faces are presented along with non-face targets. However, a more direct comparison of the effects of *perceptual load* vs. *working memory load* on face processing will require future research. One key question here will be whether the simultaneous presence of a target face more effectively abolishes distractor face processing, and thus whether an effect of perceptual load on repetition sensitive ERP components can be observed when a distractor face competes with a target face for limited attentional capacity.

Conclusion

We observed N250r and N400 ERP correlates of face repetitions even when task-irrelevant prime faces were presented under conditions of high perceptual load in a letter detection task. This suggests preserved access to facial identity and semantic information, respectively. Our results replicate and extend recent findings of remarkably preserved processing of faces presented outside the focus of attention (Bindemann, Jenkins, & Burton 2007; Jenkins, Burton, & Ellis 2002; Jenkins, Lavie, & Driver 2003; Neumann, Schweinberger, Wiese, & Burton 2007), and support notions of face-specific attentional resources.

Experimental Procedure

Participants

Twenty students (15 female) from the University of Jena, aged between 20 and 26 years (M = 21.8, SD = 1.9) contributed data to this study. All participants gave written informed consent and had normal or corrected-to-normal visual acuity. All participants were right-handed. One additional participant was excluded from the analyses because of technical problems in the EEG data acquisition. The study was conducted in accordance with the Declaration of Helsinki.

Stimuli and apparatus

Two hundred and eighty photographs of famous faces (50% female), and 40 photographs of butterflies were used in the experiment. Twelve additional famous face images were used during practice trials. Face images were obtained from different sources and were software edited using Adobe Photoshop CS2 (Adobe Systems Inc., San Jose, CA, USA). All images were converted to greyscale and placed in front of a black background. Face images were adjusted in size and oriented in a way that both eyes were horizontally aligned, with the middle of the nose at fixation. Butterfly images were taken from a stimulus set used in a previous study (Schweinberger, Huddy, & Burton 2004). To avoid exact stimulus repetitions in terms of retinal coordinates, horizontal and vertical stimulus size was 305 x 386 pixels (corresponding to a visual angle of 5.9° x 7.5°) for S1 face stimuli and 254 x 322 pixels (4.9° x 6.2°) for S2 face and butterfly stimuli. S1 letters were presented in Arial 26 font. S1 display blends consisted of letter strings, superimposed on centrally presented famous faces. Letter-strings consisted of 6 upper-case letters in red colour (cf. Figure 1), and included target letters “X” or “N” and non-target letters “H”, “K”, “W”, “M”, and “Z”. Low load letter strings consisted of target letters only (“XXXXXX”” or “NNNNNN”), whereas high load letter strings consisted of one of the target letters and the five non-target letters, arranged in random order (e.g., “HKNWMZ”). In half of the S1 displays each, the target letter was an “X” or an “N”, respectively. High and low load displays occurred in equal frequency and in randomised order.

Procedure

Participants were seated in a dimly lit, electrically shielded cabin in front of a CRT monitor at a viewing distance of 90 cm, which was kept constant by using a chin rest. The trial procedure is illustrated in Figure 1. During each experimental trial, an initial white fixation cross was presented for 1000 ms and replaced by the S1 display for 200 ms. The S1 display was replaced by another fixation cross for 2000ms. Participants responded by button press on a PST serial response box (Psychology Software Tools, Inc., Pittsburgh, PA, USA). For "N", participants pressed the left button using the left index finger, for "X", they pressed the right button using the right index finger, accordingly. Generally, speed and accuracy were emphasised. Subsequently, the S2 display was presented for 2000 ms. S2 stimuli were either a) smaller sized repetitions of the previously seen S1 face, b) new, previously unseen famous faces, or c) butterflies. Participants had to respond by button press to every occurrence of a butterfly (20% of S2 displays), but not to faces. S2 displays were followed by a black screen for 1000 ms, before the next trial was initiated. The experimental design included two variables "Load" (high vs. low) and "Repetition" (repetition vs. non-repetition), resulting in four conditions of interest: High-Load Repetition (HL-R), High-Load Non-Repetition (HL-NR), Low-Load Repetition (LL-R), and Low-Load Non-Repetition (LL-NR). A total of 200 trials were presented in randomised order (40 trials per condition, plus 40 butterfly trials); breaks were allowed after every 40 trials.

Event-related brain potentials

We recorded the electroencephalogram (EEG) using a 144 channel BioSemi Active II system (BioSemi, Amsterdam, Netherlands). Electrode positions included 128 standard BioSemi sites plus 16 inferior temporal, occipito-temporal, and occipital sites. EEG (DC to 75 Hz) was sampled at 256 Hz. The EEG was measured relative to a combined ground/reference (CMS/DRL) circuit, which is specific to BioSemi systems (cf. to http://www.biosemi.com/faq/cms&drl.htm for further information).

Trials with incorrect behavioural response (misses or false alarms) on either S1 (letter identification) or S2 (butterfly detection) stimuli were discarded. Ocular contributions were corrected using algorithms implemented in BESA 5.1 (MEGIS Software GmbH, Graefeling, Germany), and trials containing non-ocular artefacts were discarded. ERP epochs to S1 and S2 stimuli were quantified for 1400 ms (200 ms prestimulus baseline). ERPs were averaged separately for each channel and for each experimental condition. ERPs were recalculated to average reference, and were digitally low-pass filtered at 20 Hz (zero phase shift).

ERP analyses

ERPs were statistically analysed within 14 regions of interest (ROIs). Regions were: frontal medial (FM), frontal right (FR), frontal left (FL), temporal right (TR), temporal left (TL), central medial (CM), central right (CR), central left (CL), parietal medial (PM), parietal right (PR), parietal left (PL), occipito-temporal right (OTR), occipito-temporal left (OTL), and occipital medial (OM). We analysed ERPs to S1 and S2 stimuli separately by taking mean amplitudes in the time segments 80-120 ms, 140-180 ms, 180-220 ms, 220-300 ms, 300-400 ms, 400-500 ms, and 500-600 ms. Initial analyses of variance were performed with repeated measures on ROI, Load, and Repetition. Huynh-Feldt correction was applied throughout where appropriate. Significant effects of Load and Repetition in interaction with ROI were followed up by ANOVAs with repeated measures on Load and Repetition for each ROI separately.

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5. N250r ERP Repetition Effects from Distractor Faces when Attending to another Face under Load: Evidence for a Face Attention Resource

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Recently, evidence for a face-specific attentional resource was suggested, which limits simultaneous processing to only one face. In the present Experiment 1, we manipulated perceptual load using two central item types (CITs: small central buildings or unfamiliar faces). To test whether distractor face processing is effectively prevented by face targets, CITs were superimposed on large famous distractor faces. ERPs were measured to subsequent faces, which could be a repetition or nonrepetition of the previous distractor face. In Experiment 2, we used famous and unfamiliar faces as CITs under high load. For building CITs, we found common N250r repetition effects both under high and low load. For face CITs, N250r was reduced (Experiment 1) or even eliminated (Experiment 2) under high load. These findings support notions of a face-specific attentional resource which, at least under high demands, may limit processing to only one face at a time.

Keywords: repetition; face; attention; ERP; N250r; N400

Introduction

Given that human faces share highly similar spatial arrangements of the eyes, nose and mouth within an oval contour, people are astonishingly good in recognizing a great number of different faces. It has been argued by some authors that faces are being processed within a mechanism that is specific to or especially well-suited for faces. Several lines of evidences have been taken as support for the existence of such a face-specific processing mechanism. For instance, prosopagnosic patients have a deficit in overtly recognising familiar faces, even when those were highly familiar. In some cases these deficits can be remarkably specific, such that patients do not exhibit problems in learning or identifying other objects (Duchaine et al., 2004; Henke et al., 1998).

Ellis et al. (1990) made an interesting observation when measuring repetition priming from faces: Participants were faster to classify famous faces as being familiar when they had seen those faces in a previous prime phase. Crucially, this repetition priming effect occurred even when the prime task did not require identity processing of the face (i.e., sex or expression judgements). Ellis concluded that familiar faces are “impossible not to recognise”, i.e., that their identity is processed automatically. Other studies reported that faces may also have a special ability to capture attention (Ro et al., 2001; Bindemann et al., 2007b; Theeuwes & Van der Stigchel, 2006; Langton et al., 2008).

A number of studies using neuroimaging techniques reported the fusiform face area (FFA), a region in the fusiform gyrus, to respond more strongly to the presentation of faces than to other objects (Eger et al., 2005; Grill-Spector et al., 2004; Kanwisher et al., 1997; Wojciulik et al., 1998; Yi et al., 2006). Recently, evidence has been provided that the right fusiform gyrus can be activated by unconsciously perceived masked faces, suggesting that initial face, but not object, detection is an automatic process that can proceed without awareness (Morris et al., 2007). Moreover, Stone and Valentine (2007) reported categorical priming from masked famous faces which were presented for 17 ms only, when participants had to judge famous person’s occupation after seeing a famous congruent vs. incongruent prime (same vs. different occupation). This suggests that automatic face processing might exceed simple detection of faces, and may also include certain aspects of identity and semantic processing. However, it has been shown that attention and awareness, though often tightly coupled, can be dissociated (Kanai et al., 2006), and that even unconscious processes can be modulated by temporal attention to the prime (Kiefer & Brendel, 2006). Therefore, above mentioned findings that reported face processing without awareness do not necessarily answer the question whether face processing is also independent of selective attention.

Initial ERP evidence for face processing in the near absence of spatial attention has been reported for certain conditions (Heisz et al., 2006). Participants in this study performed a one-back location matching task involving previously unfamiliar faces, presented at four possible locations. Stimuli appeared in blocks of either several “novel” (i.e., different) faces, or in blocks containing one single face, which was immediately repeated for several times. The face-sensitive N170 was progressively decreased for repeated faces, but not for novel faces, at non-attended spatial locations. This result was interpreted by the authors as automatic face identity processing. Critically, attention was not directly manipulated in this study. Instead, it was assumed that selective attention has a bias to same locations. Accordingly, attending the most recent location of a stimulus was thought to cause subsequent stimuli, presented at the same location, to be always at the focus of attention.

By manipulating attention according to the Perceptual Load Theory (Lavie & Tsal, 1994; Lavie, 1995; Lavie, 2005), a number of studies provided behavioural (Jenkins et al., 2002; Lavie et al., 2003; Jenkins et al., 2003) and electrophysiological (Neumann & Schweinberger, 2008) evidence for task-irrelevant distractor face processing in conditions of massively restricted availability of attentional resources.

The Perceptual Load Theory assumes that visual perception is generally capacity-limited, but importantly, processing cannot be voluntarily withheld. Task-irrelevant material is being processed up to the point at which capacity is fully exhausted by the processing of task-relevant material. Therefore, processing of task-irrelevant material should be abolished when capacity is fully recruited by target processing (i.e., high perceptual load). On the other hand, task-irrelevant material is being processed inevitably, when spare capacity is available (i.e., low perceptual load).

Face processing in terms of interference of a flanker face on centrally presented names (Lavie et al., 2003; Jenkins et al., 2003), or long-term repetition priming from distractor faces (Jenkins et al., 2002) was observed not only under low load, but even when perceptual load in the unrelated task was high, a condition which usually prevents distractor processing. In a recent experiment (Neumann & Schweinberger, 2008), we investigated electrophysiological correlates of immediate repetition priming from distractor faces, while participants performed a letter search task involving either high or low load displays. Participants were successively presented with pairs of images. S1 (prime) displays were presented for 200 ms, and comprised of letter strings, superimposed on famous faces. A target letter ("X" vs. "N") had to be identified, which was embedded either in a string of six identical letters (low load, e.g. "NNNNNN") or in a string of 6 different letters (high load, e.g. "HKNWMZ"). S2 (probe) displays consisted of either a repetition of the distractor face, a new famous face, or an infrequent butterfly, upon which participants responded by button press. Remarkably, repetition sensitive ERP components were not affected by the amount of perceptual load in S1 displays: Specifically, repetition effects in terms of an N250r and an N400-like modulation were obtained not only under low, but also under high load, suggesting semantic processing of distractor faces under high load.

The N250r is an ERP deflection that has been consistently found for immediate face repetitions (Begleiter et al., 1995; Engst et al., 2006; Henson, 2003; Pfütze et al., 2002; Schweinberger et al., 1995; Schweinberger et al., 2002b; Schweinberger et al., 2004). It refers to a relatively more negative ERP for repeated as compared to unrepeated faces, a difference which typically peaks between 230 and 330 ms over right inferior temporal regions. This component is reliably larger for familiar than unfamiliar face repetitions (Begleiter et al., 1995; Herzmann et al., 2004; Pfütze et al., 2002; Schweinberger et al., 1995) and is thought to reflect a transient activation of facial representations for recognition (Itier & Taylor, 2004).

The N400 is a negative ERP at centro-parietal regions, and may be the best-known ERP that is sensitive to priming. N400-like components have been shown to be modulated by face repetitions (Bentin & McCarthy, 1994; Cooper et al., 2007; Schweinberger et al., 2002a). This rather late-latency ERP is thought to be related to the semantic integration of the current stimulus into the preceding context, and N400-like components were consistently found to be larger for familiar as compared to unfamiliar faces (Schweinberger et al., 1995; Eimer, 2000; Barrett et al., 1988).

While the above mentioned studies could favour automatic face processing without attention, there is also evidence against complete automaticity. According to Palermo & Rhodes (2007), automatic processing of faces does only prevail if faces are being processed in an especially rapid, non-conscious, mandatory, and capacity-free fashion.

Especially the last idea – capacity-free face processing – has been challenged by a number of recent findings. For example, an interfering influence of a famous face distractor on a central famous name target (Young et al., 1986) could be eliminated by simply adding a second face as the central target (Jenkins et al., 2003; Bindemann et al., 2005). Moreover, Bindemann et al. (2007a) showed that long-term response time (RT) priming from a flanker face could be eliminated when a single face was used as a simultaneous central item, and we demonstrated a lack of an occipito-temporal ERP priming modulation in this condition only (Neumann et al., 2007). These findings are inconsistent with an account of completely automatic face processing, and were instead interpreted in favour of a face-specific attentional resource, with a capacity limit of the processing of one face at a time.

Previous studies often manipulated perceptual load to lexical target material such as letter strings or names. However, in the context of high-level visual perception, it can be argued that there is very little overlap in the processes that code lexical stimuli and faces. Specifically, the perception of lexical stimuli may involve extensive feature decomposition, whereas the perception of faces is often characterized as holistic, and may involve virtually no explicit feature decomposition. By that account, the perception of common objects it thought to rely on a mixture of feature decomposition and holistic processing (Farah, 1991). It would therefore be of interest to determine whether, in comparison to the presence of a target letter string, the presence of a target object more effectively compromises distractor face processing.

Consequently, in our current study, we presented small photo-realistic meaningful objects (buildings and faces) as targets. Prime distractors were large famous faces, and prime target objects were presented superimposed on the distractor faces' nose region. A similar manipulation was described previously (Yi et al., 2004), but the authors of that study used natural scenes as distractors, and presented faces as targets only. However, in neuroimaging study using functional magnetic resonance imaging (fMRI), Yi et al. presented overlapping houses and faces (Yi et al., 2006). Participants attended to either stimulus category while ignoring the respective other category. Repetition effects were measured in terms of repetition attenuation from attended vs. unattended items separately. The authors found repetition to be generally affected by attention, with larger repetition effects from attended than from unattended faces and houses. However, this study differs in several aspects from the current study. First, the authors did not investigate conditions in which targets and distractors were of the same stimulus category (i.e., two overlapping faces). Moreover, their use of overlapping stimuli of the same size may draw on object-based attention rather than spatial attention. Finally, the fMRI technique offers good spatial resolution but only very coarse time resolution. Using event-related potentials (ERPs) allows us to investigate the influence of attention on face processing in great temporal detail.

In the present experiments, we employed an immediate repetition paradigm similar to the one used by Neumann and Schweinberger (2008). Prime (S1) displays contained one of two central item types (CITs: small central unfamiliar face or building targets) presented superimposed on the nose region of large famous distractor faces. Prime targets (faces and buildings) were presented in light blue or light red colour and were either old or young (cf. Figure 1). Perceptual load was manipulated by task demands: The low load task involved simple colour discrimination of target stimuli, whereas in the high load task a more demanding age classification of targets was required. During subsequent probe (S2) presentation, faces were either immediate repetitions of the previous prime distractor or new unseen famous faces. To create the task demands, a third condition was included with butterflies as S2 stimuli, to which participants were required to respond by button press.

For building CITs, we reasoned that N250r and N400 ERP repetition effects to probe faces should occur under both low and high load conditions, replicating previous findings with letter targets (Neumann & Schweinberger, 2008). By contrast, assuming the existence of a putative face-specific attention resource with a capacity limit of one face, we would expect reduced or eliminated ERP repetition effects for face CITs, particularly in conditions of high perceptual load. This is because face targets in the prime phase should exhaust the face attention resource and prevent distractor faces from being processed, hence eliminating effects of repetition at subsequent probe presentation.

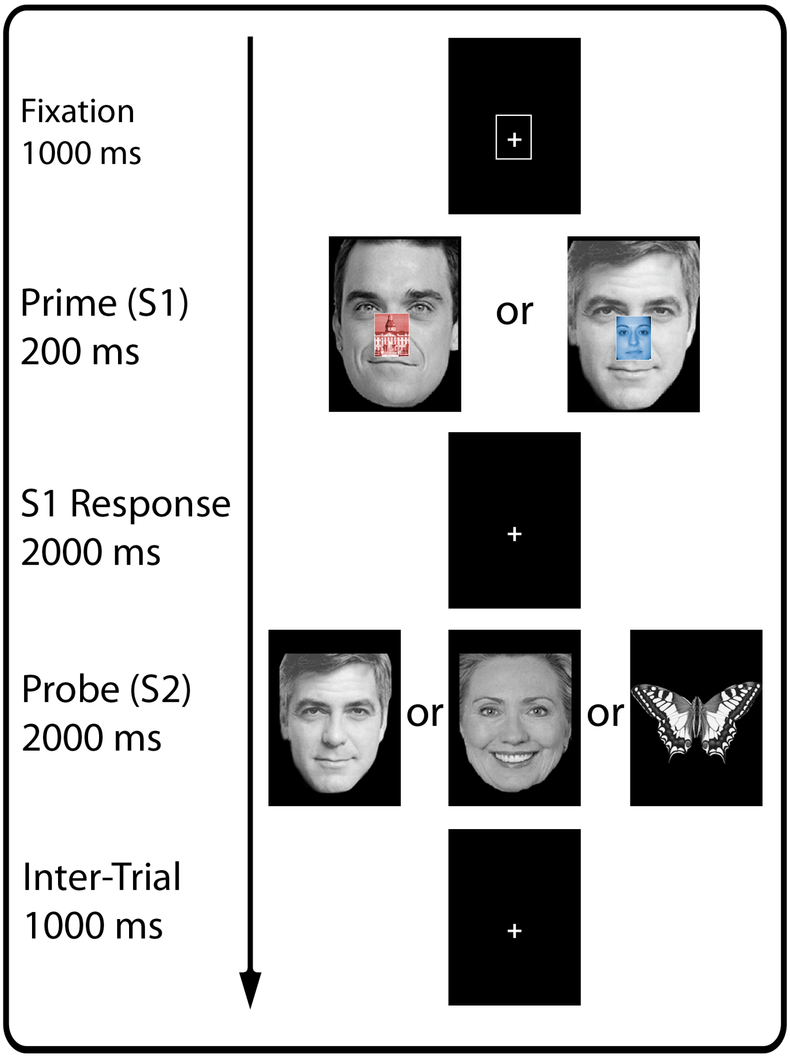

Fig. 1 General trial procedure. Primes (S1) consisted of target face or target building CITs in red or blue colour, presented superimposed on large famous distractor faces. “Young” vs. “old” responses to targets were required under high load, “blue” vs. “red” responses under low load. Left prime image: Example for building target condition (“old”/”red”); right image: Example for face target condition (“young”/”blue”). Probes (S2) were either repetitions of previously presented distractor face (left image), new famous faces (middle), or butterflies (right). Participants responded to butterflies only. Note: Stimulus size is not to scale.

Results Experiment 1

Behaviour

Responses were scored as correct if the appropriate response was given within 1800 ms (S1 targets) or 2000 ms (S2 butterflies), respectively. To assess whether load in S1 displays was manipulated successfully, we compared response times (RTs) and accuracies to primes for high and low perceptual load conditions and for the two CITs (buildings or faces). For RTs, repeated measure ANOVAs including the factors Load and CIT revealed main effects for both Load, $F(1,23) = 255.07$, $p < .001$, and CIT, $F(1,23) = 12.77$, $p < .01$. Moreover, these effects were qualified by a significant Load*CIT interaction, $F(1,23) = 12.21$, $p < .01$. Post-hoc pairwise contrasts revealed faster responses in low load as compared to high load trials ($M = 509$ ms vs. $M = 727$ ms, respectively; $t[23] = 15.97$, $p < .001$). Age decisions in high load trials were given faster to unfamiliar faces than to buildings ($M = 709$ ms vs. $M = 746$ ms for faces and buildings, respectively; $t[23] = 3.99$, $p < .001$). By contrast, RTs for colour discriminations in low load trials were equivalent for faces and buildings ($M = 510$ ms vs. $M = 506$ ms for faces and buildings, respectively; $t[23] = .74$, $p > .20$).

A similar pattern was seen for accuracies. ANOVAs including the factors Load and CIT revealed main effects for both Load, $F(1,23) = 64.62$, $p < .001$, and CIT, $F(1,23) = 21.99$, $p < .001$, with a significant Load*CIT interaction, $F(1,23) = 30.74$, $p < .001$. Participants were more accurate in low load as compared to high load trials ($M = .97$ vs. $M = .88$, respectively; $t[23] = 8.04$; $p < .001$). Age decisions in high load trials were more accurate to unfamiliar faces than to buildings ($M = .92$ vs. $M = .85$ for faces and buildings, respectively; $t[23] = 5.43$, $p < .001$). By contrast, accuracies for colour discriminations in low load trials were again equivalent for buildings and faces ($M = .97$ in both cases; $t[23] = .51$, $p > .20$).

Performance in detecting S2 butterflies was at ceiling in all conditions (> .99), and was not further analysed. In analyses of RTs to S2 butterflies the main effect of Load and the CIT by Load interaction were not significant (both $F < 1$). The main effect of CIT reached significance, $F(1,23) = 4.65$, $p = .042$, indicating very slightly delayed RTs, when previous targets were buildings compared to when they were faces ($M = 697$ ms for buildings, $M = 691$ ms for faces, respectively). Although this extremely small difference was statistically significant, we refrain from speculating about potential explanations at this point.

Event-related potentials

<u>ERPs to S2 probe faces</u>

ERPs to S2 faces at the occipito-temporal, occipital medial, and central medial regions of interest (ROIs) are illustrated in Figure 2.

P100: Mean amplitudes in the P100 time segment (80 – 120 ms) were not influenced by Load, Repetition or CIT at occipital medial ROI, all $p > .20$.

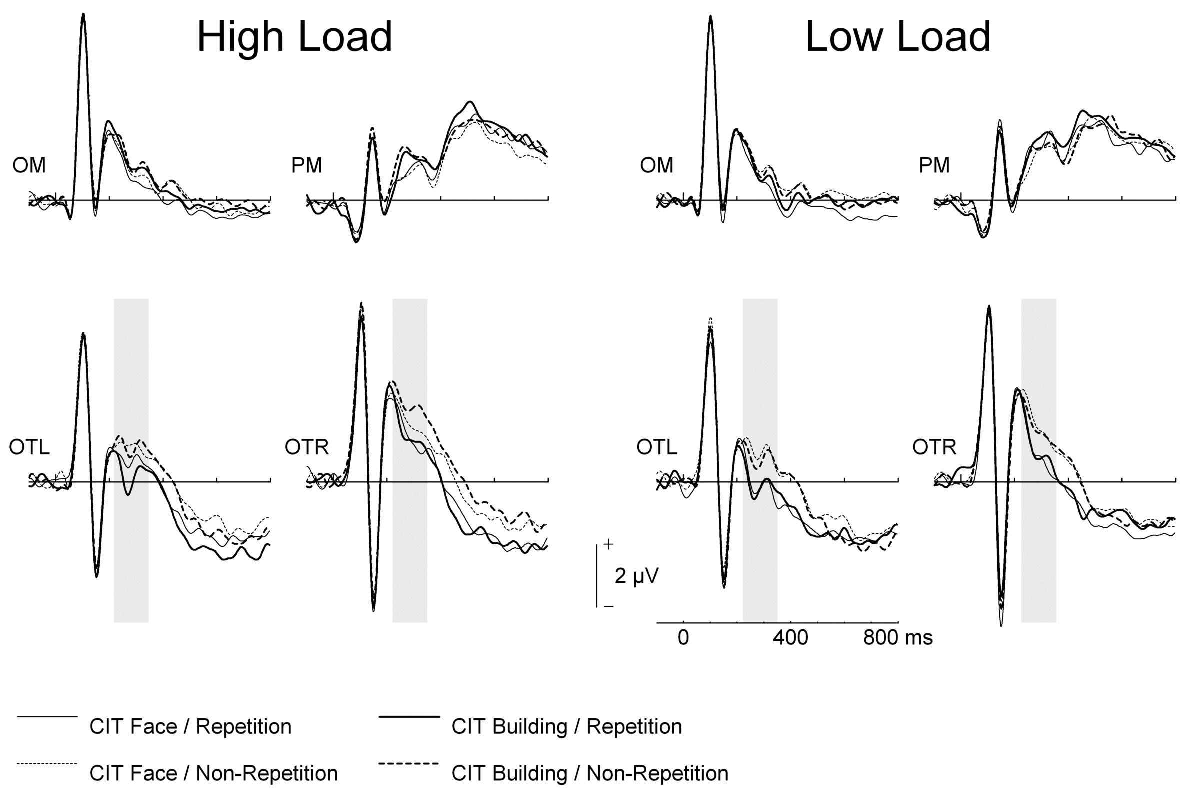

Fig. 2 ERPs to S2 faces for all CIT and Repetition conditions. Left: S1 primes were presented under high load; Right: S1 primes were presented under low load. Displayed ROIs are occipital medial and central medial (OM, CM; top row), and occipito-temporal left and right (OTL, OTR; bottom row). Gray shaded interval delimits the 220-350 ms (N250r) time interval. Please note the reduced repetition effects under high load, when target CITs were faces as compared to buildings.

N170: For mean amplitudes in the N170 time segment (130 – 170 ms), we found a significant 3-way interaction of all experimental factors Load*Repetition*CIT, $F(1,23) = 9.48$, $p < .01$ at bilateral occipito-temporal ROIs. In subsequent separate ANOVAs for high and low load conditions, no effects of any experimental condition, and no interaction, was found for high load (all $p > .10$). For low load trials, a significant CIT*Repetition interaction, $F(1,23) = 7.99$, $p < .01$, was observed. When prime CITs had been buildings, repetition effects were not significant (all $p > .10$), while in cases when prime CITs had been faces, the N170 was enhanced for repeated as compared to unrepeated prime distractor faces, $F(1,23) = 20.11$, $p < .001$.

N250r: The ANOVA for mean amplitudes in the N250r time segment (220 – 350 ms) revealed a main effect of Repetition, $F(1,23) = 11.44$, $p < .01$, reflecting more negative going ERPs to repeated than to new distractor faces, at bilateral occipito-temporal ROIs. Additionally, a main effect of Load was significant, $F(1,23) = 4.99$, $p < .05$, reflecting more negative or less positive going ERPs in low load as compared to high load trials. Moreover, the Hemisphere*Electrode*Repetition*CIT interaction was significant, $F(5,115) = 2.46$, $p < .05$, $\varepsilon = 90$. Finally, the 3-way interaction between all experimental factors Load*Repetition*CIT was almost significant, $F(1,23) = 3.66$, $p = .068$. Visual inspection suggested that repetition effects were larger for conditions including building CITs as compared to face CITs during prime presentation, if presented under high load only (cf. Figures 2 and 4a). No such differences were seen for low load CIT conditions. Repetition effects at 6 standard electrode sites for face vs. building targets are illustrated in Figure 4b. For the high load condition, repetition effects from distractor faces were reduced for face CIT as compared to building CIT conditions at all sites. In order to further investigate these effects, we calculated pair wise t-tests between repeated and unrepeated conditions at all 12 electrodes separately for both CIT conditions. Significant repetition effects were found at 5 electrodes ($p < .05$), and a trend was found at 4 additional electrodes ($p < .10$), when targets were buildings. When faces were targets, no repetition effect was found at any electrode (all $p > .10$).

N400: We analysed N400 mean amplitudes at 10 central sites including standard site Cz and 9 adjacent electrodes between 400 and 550 ms. The only significant effect we found was a main effect of Repetition, with a smaller negativity (or larger positivity) for repeated faces, $F(1,23) = 10.55$, $p < .01$ (cf. Figure 2). No additional effects including an experimental factor were significant (all $p > .10$).

<u>S1 prime displays</u>

Although we mainly focussed on ERP analyses to probe faces, which were presented without superimposed targets, we additionally analysed ERP waveforms to S1 composite displays (cf. Figure 3) using ANOVAs with repeated measures on Hemisphere (N170), Electrode, Load (high vs. low) and CIT (face target vs. building target). Please note that it is difficult to unequivocally relate the ERP to prime displays to either target CIT (face, building) or distractor (face), as these are presented simultaneously. For the purpose of the present paper, we had no specific hypotheses with respect to the responses to prime displays, and we will hence only briefly report ERP results to prime displays.

The P100 at occipital medial sites (same electrode set as for S2 stimuli) was larger for face than for building targets, $F(1,23) = 17.79$, $p < .001$. No further effects were significant (all $p > .20$).

Between 130 and 170 ms (N170), an effect of Load in interaction with hemisphere was observed, $F(1,23) = 6.48$, $p < .05$, reflecting larger N170 responses under low as compared to high load at OTL sites. No other effects were significant.

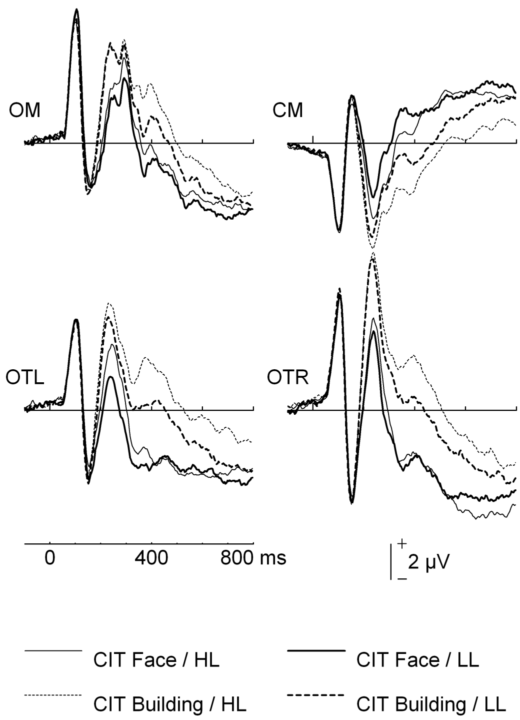

Fig. 3 ERPs to S1 prime displays for all CIT and Load conditions. ROIs as specified in Fig. 2.

Starting from ~200 ms, ERPs at various regions were strongly influenced by both load and CIT. In short, face CITs elicited much larger occipitotemporal negativity than building CITs, and especially in later time segments these effects were somewhat enhanced for the high load condition. We refrain at this point to report further statistics for these palpable modulations in later time intervals.

Discussion Experiment 1

In Experiment 1 we manipulated perceptual load to small central items in prime displays presented superimposed on the nose region of famous prime distractor faces. We assessed ERPs for repetitions of those distractor faces vs. new famous faces at probe presentation. While related previous studies often used letter strings as prime targets, we used photographs of building and face targets. Crucially, we employed conditions in which two faces were present in a prime display at the same time, one unfamiliar face target and one famous face distractor. This enabled us to test recent accounts regarding a putative face-specific attentional resource with a capacity limit of one face at a time (Bindemann et al., 2005; 2007a; Neumann et al., 2007).

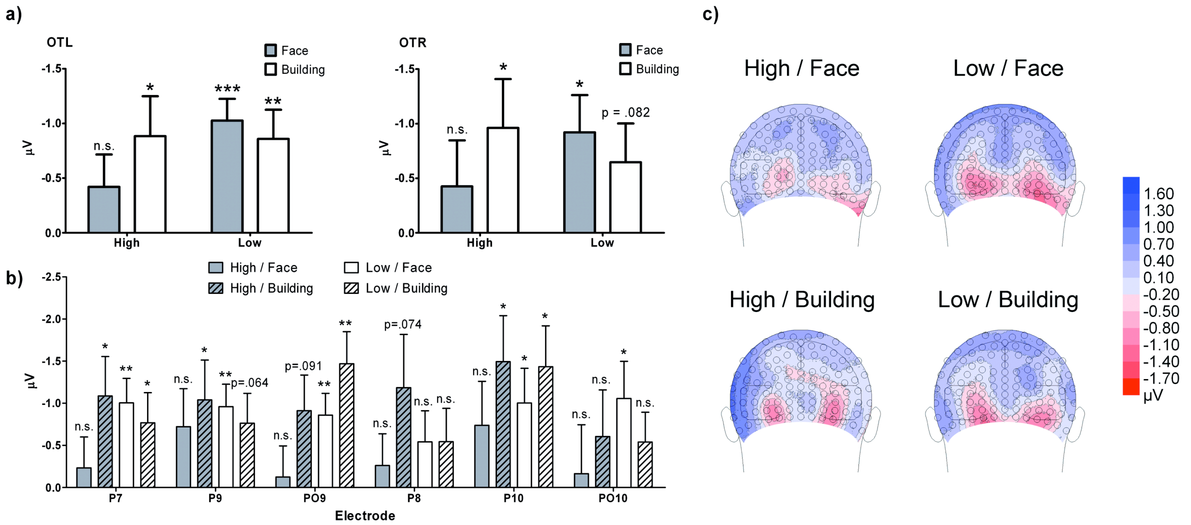

Fig. 4: Repetition effects (N250r mean amplitude differences of repetition minus non-repetition conditions at right and left occipito-temporal regions for all Load and CIT conditions (a), and at single standard electrodes P8, P10, PO10 and corresponding left-hemispheric sites (b). Voltage maps (spherical spline interpolation, 110°equidistant projection) of these effects for face (top) vs. building (bottom) targets under high and low load to S1 primes are displayed in (c). Note reduced repetition effects under high load face CITs but not building CITs in all three illustrations. Significance levels or p-values of trends are illustrated for all repetition effects, when tested individually for the respective condition.

In line with a previous study in which perceptual load to letter strings were manipulated, we found repetition effects from distractor faces for the building CIT condition in terms of an occipito-temporal N250r and a central N400-like modulation, irrespective of whether S1 primes were presented under high or low perceptual load conditions (Neumann & Schweinberger, 2008). Thus, the use of photorealistic objects as target CITs did not prevent distractor face processing. Crucially, and in line with recent assumptions of a capacity limit for faces of one face at a time, N250r repetition was found reduced for the face CIT condition. However, this finding was restricted to the high load task, which required central faces to be judged for age. When participants performed colour judgements (low load), distractor faces caused almost identical N250r effects for both CITs, suggesting that both target colour and distractor face identity was processed from the S1 prime display. One could argue that if processing of only one face at a time is possible, then repetition effects of distractor faces should have been reduced irrespective of the load status of the task. Consequently, reduced repetition effects for the face CIT as compared to the building

CIT condition should have been observed irrespective of load. However, we believe that the colour discrimination task in our study might have been accomplishable without activating face processing mechanisms for the centrally presented unfamiliar face (cf. Megreya & Burton, 2006), even though these mechanisms might have been instead recruited for the processing of the familiar distractor face. Performance measures in our experiment support this idea: While participants were faster and more accurate for faces than for buildings in age judgements, performance in the colour discrimination task was virtually identical for both CITs, suggesting that for colour discrimination no domain specific processing resources were activated. Thus, a putative face specific attentional resource was not necessarily recruited for colour judgements, and hence processing of distractors was possible and – according to the Perceptual Load Theory – inevitable.

A possible interpretation for the findings in the high load task is that building CITs might have enjoyed a general processing advantage compared to face CITs, consuming less attentional resources, and therefore allowing more extensive distractor (face) processing. However, the behavioural results in the high load task, with better performance for faces compared to buildings, strongly argue against that interpretation and suggest that, if anything, building CITs required more processing resources. In this light, the current ERP results, with large repetition effects in the building CIT condition are particularly remarkable. In contrast, we tentatively interpret the reduced N250r effects in the face CIT condition to reflect limited face-specific processing resources, in line with previous studies (Jenkins et al., 2003; Bindemann et al., 2005; Bindemann et al., 2007a).

Consistent with a number of previous studies which found the N170 to be completely insensitive to repetition (Cooper et al., 2007; Schweinberger et al., 2002b), we found no effect of repetition on the N170 to S2 faces in the majority of conditions. However, the N170 was slightly increased for repeated faces when face CITs had been presented under low load. This finding is not only at variance with the above studies, but is also in contrast with other studies, which did find N170 effects of face repetitions. Those studies more typically reported amplitude reductions for repeated faces (Itier & Taylor 2002, 2004, Jemel et al., 2003), which have been interpreted as perceptual priming. Thus, it is difficult to relate the above N170 effect to findings in the literature, and at present we are unable to offer a satisfactory explanation for this effect, which may require replication before any strong conclusions can be made.

One interesting question is why residual repetition effects, although reduced under high load, were found at all for face CIT conditions. If participants had been able to process only one face at a time, then one would expect repetition effects to be completely absent when two faces (one target and one distractor) were presented simultaneously in the face CIT condition. One possible explanation might be the use of identical images at prime and probe presentation. In line with this notion, a recent behavioural study (Bindemann et al., 2007a) found similar residual priming from distractor faces when using identical images at prime and probe. In the current study we used larger face images as S1 distractors than as S2 probes, to avoid exact stimulus repetitions in terms of retinal coordinates. Thus, while we cannot completely exclude the above explanation, mere perceptual priming caused by identical stimuli as primes and probes appears less likely in the current design.

Alternatively, the possibility needs to be considered that our use of unfamiliar target faces with famous distractor faces could have caused an involuntary attentional capture by the potentially more interesting distractors (Stone & Valentine, 2005). Recent studies pointed out that processing of familiar faces differs severely from processing of unfamiliar faces (e.g., Megreya & Burton, 2006), and that familiarity might be one important factor that determines how much attention is needed for natural scene categorization (Li et al., 2005). In line with these ideas, unfamiliar face CITs in Experiment 1 might have been processed rather like objects than faces, thus drawing on more general attentional resources.

In Experiment 2, we therefore tested the influence of familiarity status of face CITs by measuring priming from distractor faces when randomly intermixed famous vs. unfamiliar target faces were judged according to age (high load). Our hypothesis was that N250r effects would be completely eliminated for famous face CITs, as famous faces can be expected to be mandatorily processed for identity irrespective of task (Ellis et al., 1990).

Results Experiment 2

<u>Behaviour</u>

We calculated ANOVAs with repeated measures on CIT and Target Age (TA; old vs. young). For RTs to prime faces, only the main effect of CIT was significant, $F(1,19) = 7.46$, $p < .05$, reflecting slightly faster responses to famous than to unfamiliar faces ($M = 676$ ms vs. $M = 689$ ms, respectively).

In accuracies to prime faces, a significant interaction of CIT*TA was found, $F(1,19) = 10.38$, $p < .01$. Participants were more accurate to judge unfamiliar old faces than unfamiliar young faces ($M = .94$ vs. $M = .84$ for old and young faces respectively). In contrast, age judgements were not significantly different for famous faces ($M = .90$ vs. $M = .91$ for old and young faces respectively).

Detection accuracy (hit probability) for S2 butterflies was at ceiling in all conditions (> .99), and was not further analysed. Likewise, no significant effects of CIT or TA were found in response times to S2 butterflies, and there was no interaction (all $p > .10$).

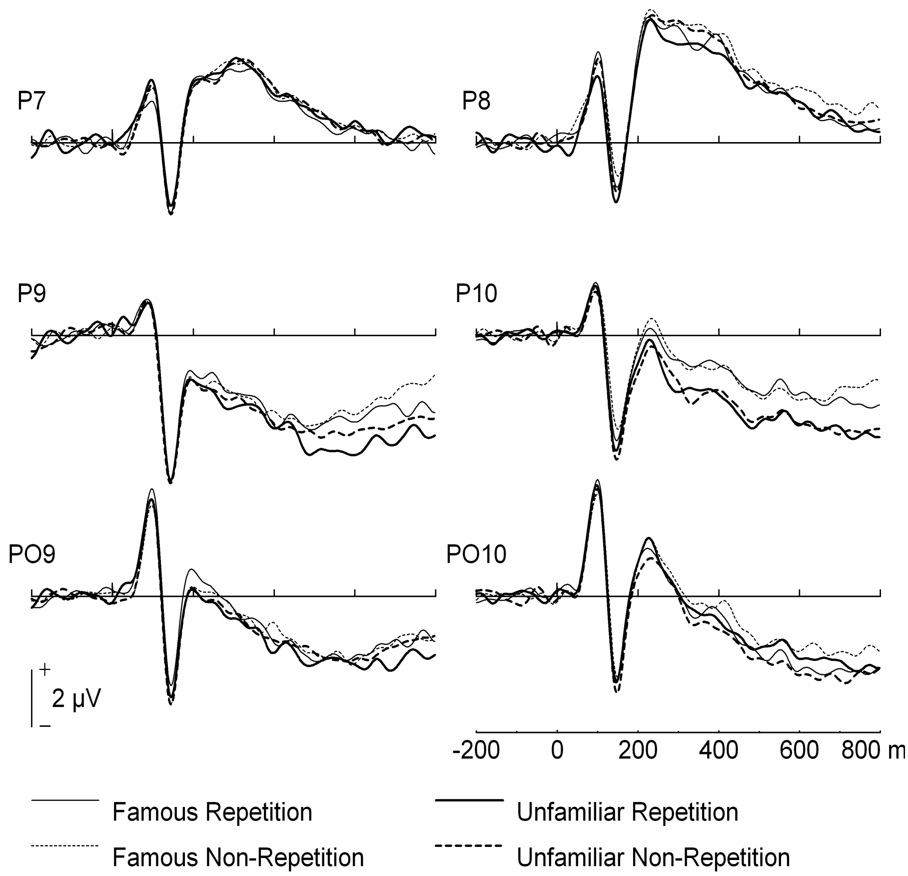

Fig. 5 ERPs to S2 faces in Experiment 2. Displayed are all CIT (famous, unfamiliar) and repetition conditions at 6 occipito-temporal electrodes. The grey shaded interval delimits the 220-350 ms (N250r) time interval. Please note that repetition effects were absent at most electrodes, and a marginal repetition effect was seen only at P8, for unfamiliar CITs.

Event-related potentials

In general, ERP analyses were carried out in an analogous manner as in Experiment 1.[1] The factorial design included CIT (famous vs. unfamiliar) for S1 analyses, and CIT and Repetition (repetitions vs. non-repetitions of distractor faces) for S2 analyses. For S1 displays, effects of CIT in an initial global ANOVAs including all 32 channels are always reported in interaction with electrode.

S2 faces (probes)

Maximum positive peaks between 90 and 130 ms (P100) were observed at O1 and O2 electrodes. A main effect of CIT was found at these electrodes, $F(1,19) = 7.27$, $p < .05$, reflecting slightly larger P100 to S2 faces preceded by prime displays containing famous as compared to unfamiliar face CITs.

The N170 amplitude between 130 and 170 ms peaked at P9 and P10. The ANOVA with repeated measures on Hemisphere, Repetition, and Familiarity for these electrodes revealed no main effects or interaction including an experimental factor (all $p > .10$).

Potential repetition effects referring to a N250r were analysed using an ANOVA with repeated measures on hemisphere, electrode (P8, P10, PO10, and corresponding left-hemispheric sites), and experimental factors Repetition and Target Familiarity (TF) for mean amplitudes in the interval between 220 and 350 ms. The only significant effect involving one of the experimental factors was a main effect of CIT, $F(1,19) = 11.23$, $p < .01$, reflecting more negative going ERPs when prime CITs were unfamiliar. Most remarkably, no main effect and no interaction involving Repetition was significant, all $p > .20$.[2] Thus, in strong contrast to Experiment 1, no reliable N250r effect could be observed in Experiment 2.

No clear N400 repetition-modulation emerged in the 400-550 ms time segment. An ANOVA for midline parietal and central electrodes Cz and Pz revealed a trend for

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[1] Note that we used a 32-channel EEG system in Experiment 2, due to temporary unavailability of the 144-channel system. We considered this to be acceptable, as we did not test specific hypotheses with respect to source localisation of the components involved. In addition, apart from the number of channels the 32-channel system had identical technical specification as the system used in Experiment 1. Thus, for the purpose of the present report, these differences should not substantially affect the comparability of data from the two experiments.

[2] Visual inspection of Fig. 5 suggests a possible small repetition effect at P8 for unfamiliar face CITs only. When P8 was tested alone, there was no evidence for N250r repetition effects for famous face CITs, $p > .20$, although there was a marginal effect for unfamiliar face CITs, $t = 1.99$, $p = .061$.

an Electrode*Repetition interaction, $F(1,19) = 3.76$, $p = .068$. Follow-up ANOVAs carried out separately for both electrodes confirmed this weak trend for Repetition at Cz only, $F(1,19) = 3.28$, $p = .086$, again with slightly smaller negativity (or larger positivity) for repeated faces. No such effect was seen at Pz ($F < 1$). Crucially, no interaction of Repetition and CIT was observed (all $p > .10$).

S1 prime displays

Analogous to Experiment 1, we analysed ERPs to S1 composite displays. Again, the fact that displays were complex composites of two faces made it difficult to relate ERP responses to either of these stimuli. However, here we tested the influence of familiarity of a face on ERP responses.

Both P100 and N170 were not affected by familiarity (all $F < 1$).

However, for the time interval between 220 and 350 ms an overall ANOVA including all 32 electrodes revealed a main effect of CIT, $F(1,19) = 4.60$, $p < .05$. Separate ANOVAs for all electrodes located significant CIT modulations at right parieto-temporal sites P10 and TP10 (both $p < .01$), with more negative ERPs to famous than unfamiliar face CITs. The only other sites with significant CIT effects were left occipital (O1, $p < .05$), and left frontal (F7, $p < .01$).

Discussion Experiment 2

In Experiment 2 we sought to determine whether residual repetition effects in the face CIT condition in Experiment 1 were due to the fact that we had combined unfamiliar face CITs with famous distractor faces. In Experiment 2, we therefore presented unfamiliar and famous face CITs, while measuring repetition effects from famous distractor faces. First, N250r or N400 repetition effects were completely absent for famous face CITs. This finding would seem to confirm our hypothesis that distractor face processing would be eliminated by famous face CITs, which presumably capture attention and are mandatorily processed for identity.

However, unfamiliar face CITs also did not give rise to a substantial and significant N250r in Experiment 2, which is at some variance both with our hypothesis and the results from the analogous condition in Experiment 1. If anything, only a small local influence of repetition for unfamiliar face CITs was seen at P8 in the N250r time region. No other occipito-temporal electrode was sensitive for repetition of a distractor face, irrespective of whether target faces were famous or unfamiliar. In general, this finding supports the idea that only one face can be processed at a time. It remains unclear, though, why we obtained repetition effects in this condition in our Experiment 1. While we had expected repetition effects to emerge for unfamiliar but not for famous face CITs, there was preliminary support at best for this idea.

Potential reasons for the discrepancies in the results of our two experiments include the fact that CITs in Experiment 1 were presented in blue or red colour in order to implement a low perceptual load task involving colour judgments (cf. Lavie, 1995). Availability of monochrome colour information may have caused attentional pop-out of CITs in Experiment 1. Thus, discrimination between CITs and distractors in Experiment 1 may have been easier, reducing general load in Experiment 1, accordingly. However, as RTs for age decisions to face CITs were numerically faster in Experiment 2 than for analogous condition in Experiment 1, this does not appear to be a likely explanation. Alternatively, the randomised trial presentation of famous and unfamiliar face CITs in Experiment 2 might have caused participants to attempt to identify all face CITs, thus reducing distractor face processing for both famous and unfamiliar CITs. Although this is clearly a post-hoc explanation at present, it would be interesting for future research to see whether N250r effects could be reinstated in a design in which CIT is varied in a blockwise (rather than randomised) fashion.

Unexpectedly, we found P100 amplitude to S2 faces modulated by the familiarity status of the corresponding face CIT. P100 amplitudes were slightly larger, when preceding face CITs were famous. P100 amplitudes are modulated by attention (Clark & Hillyard, 1996), with larger amplitudes reflecting greater attentional allocation to a stimulus. Accordingly, this finding might reflect a mechanism by which a famous face CIT leads to a slightly increased attentional allocation to subsequent stimuli.

Overall, the absence of N250r and N400 effects in Experiment 2 demonstrates that distractor face processing can be effectively prevented in a condition of high load by using famous faces CITs.

General Discussion

In two experiments, we tested whether previously reported ERP correlates of repetition priming by task-irrelevant distractor faces can emerge under situations of high load in a task involving real-life target objects (buildings and faces). According to the Perceptual Load Theory, processing of distractors should occur in low, but not in high perceptual load conditions. By contrast, in Experiment 1 we found distractor face processing in terms of N250r and N400 repetition effects, irrespective of perceptual load to object CITs. This is in line with studies reporting behavioural priming or neural repetition effects in these ERP components, even when processing of first face presentations occurred under high perceptual load in a letter search task (Jenkins et al., 2002; Neumann & Schweinberger, 2008). These findings have been tentatively interpreted in favour of the existence of a separate face-selective attentional system.

It was further suggested that the putative face-selective attentional system is capacity-limited to the processing of only one face at a time (Bindemann et al., 2007a; Bindemann et al., 2005; Neumann et al., 2007). If these assumptions are appropriate, distractor face processing should be effectively prevented by using an unrelated task that involves face CITs, rather than letter strings during prime presentations. Experiment 1 provides some initial evidence for reduced repetition effects from distractor faces when face CITs were displayed. Strikingly, Experiment 2 demonstrates that N250r and N400 repetition effects from distractor faces can be completely eliminated by using famous face CITs, which may be more potent to capture attention compared to unfamiliar face CITs used in Experiment 1.

Previous studies typically used letter strings or other lexical material as targets, which were either superimposed on, or presented next to, distractor faces. Although lexical material in principle provides a well-controllable opportunity to manipulate perceptual load, letter processing arguably may be too dissimilar from face processing (Farah, 1991), thus allowing for parallel processing of letters and faces. It is thus important that Experiment 1 demonstrated that meaningful object (building) CITs still resulted in N250r and N400 repetition effects from distractor faces, perhaps suggesting separate attentional modules, or channels, for objects and faces.

In line with the idea of separate processing channels for letters and faces, Awh et al. (2004) reported a short period of reduced temporal attention to a subsequent letter target (T2), when previously a letter target (T1) had to be identified ("Attentional Blink"). However, when a face occurred as a T2 stimulus, the attentional blink effect was absent, suggesting intact face processing. The authors concluded that face and letter processing takes place in separate channels, arguing against a central bottleneck in visual perception. Crucially, the authors found that presenting face targets as both T1 and T2 stimuli resulted in an attentional blink effect. Presenting a T1 face obviously occupied the channel specifically used for face processing. This finding is in line with our current results of reduced distractor processing when simultaneously presenting a target face superimposed on a distractor face. Awh et al. were able to replicate this effect using “greebles” as either T1 or T2 stimulus. Greebles are objects that are thought to evoke configural codes, as faces do (Farah et al., 1998). The authors concluded that configural processing of faces and greebles is carried out in a “perceptual channel” that is separate from the channel used for feature-based processing of, for example, letters. It might be worthwhile for future studies to investigate if such a dissociation of separate configural vs. feature-based processing capacities, as reported by Awh et al. for temporal attention (attentional blink), also applies to spatial attention (manipulation of perceptual load) in face processing. For example, it would be interesting to see if priming from distractor faces in our paradigm could be reduced or eliminated when greebles were presented as targets, or vice versa.

More indirect evidence for separate attentional resources, or modules, comes from a series of recent studies investigating the influence of working memory load on selective attention using faces or objects (Gazzaley et al., 2005; Yi et al., 2004; Sreenivasan & Jha, 2007; Park et al., 2007). An initial study (de Fockert et al., 2001) measured interference from an incongruent vs. congruent distractor face on simultaneously presented names. At the same time, participants performed a working memory task, which was either demanding (high memory load) or easy (low memory load). Strikingly, enhanced distractor interference was found in conditions of high working memory load, essentially the opposite pattern that has typically been found for perceptual load manipulations. The authors reasoned that the availability of working memory is crucial for directing attention to relevant vs. irrelevant stimuli in a selective attention task. Thus, high working memory load reduces participants’ ability to distinguish between targets and distractors, resulting in increased distractor processing. Lavie et al. (2004) followed that rejecting distractors depends on at least two separable mechanisms, a passive perceptual selection mechanism analogous to the one described in the Perceptual Load account, and a cognitive control mechanism, which actively minimises intrusion from distractors.

In a recent study, Park et al. (2007) presented displays in which faces were positioned in the centre of houses, and vice versa. Participants performed a matching task: Half of the participants matched the faces from two simultaneously presented face/house composites; the other half matched the houses, accordingly. Critically, while performing the matching task, participants had to memorise either two target-congruent items (faces for the face-group, houses for the house-group), distractor-congruent items (houses for the face-group, faces for the house-group), or no items. Park found increased distractor processing under target-congruent memory load, consistent with results of de Fockert et al. (2001), but reduced distractor processing under distractor-congruent memory load. This demonstrated that working memory load must share common processing mechanisms with the target in the selective attention task in order to cause increased distractor processing under high working memory load. Park et al. (2007) argued in favour of a multiple-resource view of attention and formulated a specialised load account with respect to the interaction of working memory and attention. Accordingly, separate mechanisms are involved in the processing of face and house stimuli, and task interference occurs only when working memory task items and attention task targets share common processing resources.

A related study (Morgan et al., 2008) explored the influence of working memory load on face sensitive ERP components (N170, N250r, and the memory-related P3b). All these components were modulated by working memory load (1-4 faces were presented simultaneously and had to be memorised). Most relevantly, both N170 and N250r amplitudes to a test face were found to be reduced when encoding was under high working memory load (e.g., 2, 3, or 4 faces presented simultaneously instead of only one single face). Compatible with our results, the N170 and N250r decrease was largest between Load 1 (one face memorised) and Load 2 (two faces memorised), while no significant decrease was observed between Load 2 and Load 4. These findings may be in line with notions that processing of more than one face at a time is hard to accomplish. Here, we provide evidence that the N250r reduction might be due to an attentional capacity limit for face processing.

Conclusion

In this study, we demonstrate N250r and N400 ERP repetition effects from famous distractor faces under high load in an object processing task (Experiment 1). This extends previous findings (Neumann & Schweinberger, 2008) using letter strings. Crucially, by using unfamiliar face CITs instead of building CITs, these effects were reduced (Experiment 1) under conditions of high load. Moreover, N250r and N400 ERP repetition effects were abolished when displays included famous face

CITs (Experiment 2). These findings are in line with recent assumptions regarding prioritised but capacity-limited face processing (Bindemann et al., 2005, 2007), and further support notions of face-specific attentional resources.

Experimental Procedure

Experiment 1

Participants

Twenty-four participants (5 male, all students from the University of Jena) contributed data to the present study, Mean age = 21.0 years. Data from 5 additional participants had to be excluded due to a technical error, and data from one further participant had to be excluded due to poor EEG quality. All participants gave written informed consent and had normal or corrected-to-normal visual acuity. All participants were right-handed according to an adapted version of the Edinburgh Handedness Inventory (Oldfield, 1971).

Stimuli and apparatus

In the current experiment, we used 280 photographs of famous faces (50% female), 108 unfamiliar (non-famous) faces from the Cal/Pal Face Database (Minear & Park, 2004), 108 unfamiliar buildings, and 40 photographs of butterflies. Twelve additional famous face images were used during practice trials. Each image was presented twice during the course of the experiment (once each in the high and low load block, respectively). Famous faces and unfamiliar buildings were obtained from different sources and were software edited using Adobe Photoshop CS2 (Adobe Systems Inc., San Jose, CA, USA). All famous faces were converted to greyscale and placed in front of a black background. They were adjusted in size and oriented in a way that both eyes were horizontally aligned, with the middle of the nose at fixation. Butterfly images were taken from a stimulus set used in a previous study (Schweinberger et al., 2004). To avoid exact stimulus repetitions in terms of retinal coordinates, horizontal and vertical stimulus size was 305 x 386 pixels (corresponding to a visual angle of 5.9° x 7.5°) for S1 face stimuli and 254 x 322 pixels (4.9° x 6.2° visual angle, VA) for S2 face and butterfly stimuli. S1 target (buildings and unfamiliar faces) size was 80 x 100 pixels (1.6° x 1.9° VA), and targets were presented superimposed over the nose region of the famous distractor face. Target faces and buildings were in 50% old, and in 50% young. In the case of age classification of target buildings, participants were instructed to respond “old” for a “classical” style building, and "young" for a "modern" style building. Half of each category was colourised in light red, the other half in light blue colour, such that we used 25% red/old, 25% red/young, 25% blue/old, and 25% blue/young target images.

Procedure

Participants were seated in a dimly lit, electrically shielded and sound-attenuated cabin (IAC™CT-400) in front of a CRT monitor at a viewing distance of 90 cm, which was kept constant by using a chin rest. The trial procedure is illustrated in Figure 1. During each experimental trial, an initial white fixation cross, surrounded by a 1 px white frame in the size of the target, was presented for 1000 ms and replaced by the S1 display for 200 ms. The S1 display was replaced by another fixation cross for 2000ms. Participants responded by button press on a PST serial response box (Psychology Software Tools, Inc., Pittsburgh, PA, USA). The response button layout was counterbalanced. During low load trials, participants performed a colour discrimination task (red vs. blue) to small centrally presented targets. During high load trials, they judged targets according to age (young face / "modern" building vs. old face / "classic" building). Load was blocked and the order of high load and low load blocks was counterbalanced: Half of the participants started with the low load (colour detection), the other half with the high load (age detection) task. Speed and accuracy were emphasised.

With a stimulus-onset asynchrony (SOA) of 2000 ms relative to S1, the S2 display was presented for 2000 ms. S2 stimuli were either repetitions of the previously seen famous S1 distractor face, new and previously unseen famous faces, or butterflies. In order to avoid contributions of response-related brain activity to the ERPs to all S2 faces, participants responded by button press to occurrences of an S2 butterfly only (20% of S2 displays). S2 displays were followed by a black screen for 1000 ms, before the next trial was initiated. The experimental design included three factors "Load" (high vs. low), Central Item Type (CIT; building vs. face) and "Repetition" (repetition vs. non-repetition). In each load block, 200 trials were presented in randomised order (40 trials per condition, plus 40 butterfly trials). Breaks were allowed after every 40 trials.

Event-related brain potentials

We recorded the electroencephalogram (EEG) using a 144 channel Biosemi Active II system (Biosemi, Amsterdam, Netherlands). Electrode positions included 128 standard Biosemi sites plus 16 inferior temporal, occipito-temporal, and occipital sites. EEG (DC to 75 Hz) was sampled at 256 Hz. Trials with incorrect or missing behavioural response on either S1 (colour detection or age classification) or S2 (butterfly detection) stimuli were discarded. Ocular contributions were corrected using algorithms implemented in BESA 5.1 (MEGIS Software GmbH, Graefeling, Germany), and trials containing non-ocular artefacts were discarded. ERP epochs to both S1 and S2 stimuli were quantified for 1400 ms (200 ms pre-stimulus baseline). ERPs were averaged separately for each channel and for each experimental condition. ERPs were recalculated to average reference, and were digitally low-pass filtered at 20 Hz (zero phase shift).

ERP analyses

For ERPs elicited by S2 faces, we calculated mean amplitudes in time segments 80-120 ms (occipital P100), 130-170 ms (occipito-temporal N170), 220-350 ms (occipito-temporal N250r), and 400-550 ms (centro-parietal N400). We analysed these components at respective standard regions of interest (ROIs). The P100 was quantified at occipital medial (OM) sites, N170 and N250r were quantified at bilateral occipito-temporal (OTL, OTR) sites, and N400 was measured at central medial sites (CM). The analysed ROIs contained either 6 (OTR, OTL), 9 (OM), or 10 (CM) individual electrodes. For P100 analyses, 9 occipital electrodes including standard sites O1, Oz, O2, Iz, and 5 adjacent sites were selected. For N170 and N250r analyses, we chose a cluster of 6 electrodes per hemisphere, including standard sites at which these components are typically measured (P7, P8, P9, P10, PO9, PO10) plus 6 adjacent sites. Finally, N400 analyses were performed on a cluster of 10 central electrodes, including positions Cz, C1, C2, and 7 adjacent sites. Analyses were carried out using repeated measures ANOVAs with factors Hemisphere (right vs. left; for N170 and N250r components only), Electrode (6-10 levels), Load (high vs. low), Central Item Type (CIT: face vs. building) and Repetition (repetition vs. non-repetition). Huynh-Feldt correction was applied throughout where appropriate.

Additionally, and analogous to a previous study (Neumann & Schweinberger, 2008) we analysed ERPs to S1 prime displays. Specifically, we analysed P100 and N170 using time segments and regions as for S2 displays.

Experiment 2

Participants

Twenty participants (2 male, all students from the University of Jena), who had not participated in Experiment 1, contributed data, Mean age = 21.1 years. All participants gave written informed consent and had normal or corrected-to-normal visual acuity. All participants were right-handed according to an adapted version of the Edinburgh Handedness Inventory (Oldfield, 1971). Two additional participants were excluded from analyses, one because of age exceeding the average age by almost 20 years, and one due to problems in EEG acquisition.

Stimuli and apparatus

We used the sets of unfamiliar faces and butterflies from Experiment 1. Additionally, we created a set of 108 famous face targets by choosing images of celebrities' faces that received highest recognition scores from 10 new participants in a pre-test. Stimulus size and presentation was identical to Experiment 1, except that we used greyscale targets instead of colour targets, since load was not manipulated in this experiment.

Procedure

The procedure was identical to Experiment 1, except that participants always performed the age decision task to famous and unfamiliar face CITs. The experimental design included the factors CIT (famous vs. unfamiliar face) and Repetition (repetition vs. non-repetition). Two hundred trials were presented in randomised order (40 trials per condition, plus 40 butterfly trials). Breaks were allowed after every 40 trials.

Event-related brain potentials

We recorded the electroencephalogram (EEG) using a 32 channel Biosemi Active II system (Biosemi, Amsterdam, Netherlands). Electrode positions were Fz, FP1, FP2, F3, F4, F7, F8, F9, F10, FT9, FT10, Cz, C3, C4, T7, T8, TP9, TP10, Pz, P3, P4, P7, P8, P9, P10, PO9, PO10, O1, O2, Iz, I1, and I2. The EEG was continuously sampled at 512 Hz (DC to 120 Hz).

ERP analyses

Within the limits of reduced spatial sampling in Experiment 2, general ERP analyses were carried out in an analogous manner as in Experiment 1. Specifically, P100 was quantified at O1 and O2, N170 was quantified at P9 and P10, N250r was measured at P8, P10, and PO10 and corresponding left hemispheric sites, and N400 was quantified at Cz and Pz.

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6. General discussion

The scope of this thesis was to examine the role of attention in face processing, focussing on neural correlates of repetition effects caused by task-irrelevant faces.

Most pertinent to this research were two previous findings. First, Jenkins and co-workers (2002) recently reported relatively deep distractor face processing in terms of repetition priming that involved an image change between prime and probe presentations, when distractor faces were presented in a condition of high perceptual load. This finding suggests the existence of an attentional resource that might be especially well suited, or even specific, for the processing of face stimuli. Second, additional behavioural research (Bindemann et al., 2005; Bindemann, Jenkins et al., 2007) suggested that this putative face-specific attention resource might be capacity limited in itself, such that processing of only one face can be accomplished at a time.

Initially, this general discussion section summarises and discusses the results obtained from a total of 6 experiments that were conducted in order to replicate and extend these new results, and to provide neural markers for the mechanisms underlying long-term repetition priming (research strand 1), or immediate repetition priming (research strand 2) by unattended faces. Another section contemplates ERP components that were suggested to be sensitive for attention and/or repetition (i.e., the P100, N170, N250r, and N400) in previous research (6.4). Additionally, questions more generally related to this work are considered. More specifically, the role of eccentricity on distractor processing (6.3), and alternative perspectives on processing by presumably unattended faces are considered (6.5). Finally, it is discussed whether the special status of faces can be aligned with the strict Perceptual Load Theory, or whether a revision of this account might be required (6.6).

6.1. Long-term repetition effects from unattended faces

Three experiments (Neumann et al., 2007) directly approached the question of whether processing one face exhausts a putative face-specific attention resource and thus eliminates distractor face processing. The term “long-term” priming is used here in contrast to immediate repetition priming, and refers to the fact that prime and probe presentations were separated by a time period of 5 to 20 minutes. In the priming phases, participants performed speeded gender judgements to famous face or gender symbol central item types (CITs), which were flanked by famous distractor faces. Target CIT – distractor face pairings were either congruent or incongruent with respect to the response category. During subsequent probe presentations, participants made speeded fame judgements to previously seen (primed) or new (unprimed) famous faces. Neural and behavioural repetition effects from distractor faces and face CITs, and interference effects in response times (RTs) were assessed.

In Experiment 1, repetition priming in RTs was found for faces primed by attended face CITs, but not for faces primed by flanking distractor faces, irrespective of central item type (i.e., gender symbol vs. face). This pattern is in contrast to Bindemann (2007), who found behavioural repetition priming from distractor faces, when presented alongside non-face CITs. Nonetheless, as evident in the RT data, judging a face was much easier than judging rotated gender symbols according to sex in Experiment 1. Accordingly, the rotation process (i.e., presenting gender symbols, but not faces, rotated in steps of 30°) selectively increased the difficulty of the gender decision for symbols compared to the same task for faces. Most importantly, the presence of a congruency effect on symbol CITs, but not on face CITs, supported the initial idea that face distractors were processed as long as the target CIT was not an additional face. However, this processing did not lead to significant long-term repetition priming from these distractors, possibly due to the greater task difficulty for symbols than for faces. The fact that congruency effects on symbol CITs were observed, suggesting effective distractor face processing under this condition, is particularly striking when considering that the task was much more demanding than the same task for face CITs, where no evidence for face distractor processing was found. From the Perceptual Load Theory's perspective, higher demands of the central task should reduce lateral distractor processing. However, it has been demonstrated that variation in an irrelevant stimulus dimension can interfere with the perception of a relevant dimension even when the relevant dimension was much more difficult to perceive (Schweinberger, Burton, & Kelly, 1999). From this perspective, the current finding of intact interference even when the central task was highly demanding appear not exceptional.

In order to align gender task difficulty for faces and symbols, Experiment 2 employed upright (non-rotated) versions of gender symbols only. As a result, RTs to symbol CITs were shorter than in Experiment 1 (cf. Neumann et al., 2007, Fig. 2). However, reliable repetition priming was again received only from attended face CITs. RT priming from distractor faces remained absent irrespective of CIT. Nevertheless, similar to Experiment 1, and even more pronounced, interference on symbol CITs was observed.

Critically, the large number of trials presented in both Experiments 1 and 2 led to a very long time interval between the prime phase and probe phase, when compared to the rather small number of 60 items used in another study (Bindemann, Jenkins et al., 2007). Thus, a considerable number of intervening items were presented during this interval before repetition could occur, which had probably reduced overall repetition effects (from both face CITs and face distractors). Furthermore, decreasing task demands for symbol target conditions from Experiment 1 to Experiment 2 numerically increased interference effects. However, the gender decision task was still more demanding (that is, RTs were prolonged) for symbol than for face CITs.

To control for these caveats, some changes were applied in Experiment 3. First, the delay between prime phase and test phases was reduced, and was now more comparable to Bindemann et al. (2007). Second, more salient gender icons were used (cf. Neumann et al., 2007, Fig. 1) to render the gender task performance equal for symbol and face CITs. Third, additionally recording event-related potentials provided a potentially more sensitive method for measuring repetition effects than response times (Heil & Rolke, 2004).

Apart from the absence of a main effect of CIT, suggesting successful alignment of gender task difficulty for faces and symbols, no change was seen in the behavioural pattern compared to Experiments 1 and 2. A small congruency effect from distractor faces on symbol CITs, but not on face CITs, as well as repetition priming from face CITs, but not from distractor faces, was found.

In contrast, ERPs revealed evidence for repetition effects in terms of an occipito-temporal negativity between 400 and 600 ms from distractor faces flanking symbol CITs relative to the unprimed condition. Critically, this modulation was absent for distractor faces flanking face CITs, thus revealing first neural evidence for a putative face-specific attention resource with a capacity limit of one face at a time.

Overall, Strand 1 supported the initial hypotheses to some extent, as we found consistent congruency effects for distractor face processing when target CITs were symbols, but not when target CITs were faces. However, the behavioural and neural correlates of repetition effects from distractor faces were inconsistent. While ERPs revealed modulations between 400 and 600 ms in symbol CIT conditions, RT priming consistently remained absent, which is in contrast to both Bindemann et al. (2007) and Jenkins et al. (2002). Accordingly, main differences between these studies and the present experiments should be discussed that might account for these discrepancies.

As mentioned above, a larger set size of faces was used in the present series of experiments when compared to both previous studies. The use of a larger set size also led to longer delays between prime and probe presentations. Although it has been shown that intervening items can dramatically accelerate the decay of activation required for *semantic* priming to occur (Burton et al., 1990), *repetition* priming has been reported even when an unrelated task separated prime and probe presentations (i.e., name recognition, cf. Jenkins et al., 2002). Similarly, Joyce and Kutas (2005) reported above-chance performance in implicit face recognition even after delays of up to 1 week. However, in that study prime faces were attended and actively encoded, while prime faces were distractors in the present series of experiments, and subjects were instructed to actively ignore the flanking distractor faces. Although an explanation based on delay cannot be entirely ruled out, it might not be the sole reason for the absence of repetition priming from distractor faces in the present series of experiments.

An alternative explanation is related to overall familiarity of the celebrities used in the studies. In the current experiments, each celebrity's image was only used once as a prime, and once as a probe. Accordingly, images from 216 different celebrities were used, in contrast to only 80 different images used by Bindemann (2007). This may have affected the average familiarity of the respective face sets used. Repetition priming is typically found more pronounced from familiar than from unfamiliar faces (Schweinberger, Pickering, Burton et al., 2002; but see Goshen-Gottstein & Ganel, 2000). Thus, it is likely that the ratio of unrecognised celebrities was higher in Strand 1 than in previous studies, which in turn reduced overall RT repetition priming, and may even have eliminated distractor priming entirely. Indeed, RT repetition priming for (attended) face CITs was numerically smaller throughout the experiments of Strand 1 (~50 ms, Neumann et al., 2007) when compared to the effects that were previously reported (up to 90 ms, Bindemann, Jenkins et al., 2007), thus suggesting reduced overall priming.

Alternatively, the more difficult gender decision task for symbol CITs than for face CITs in Experiments 1 and 2 may have resulted in greater attentional demands for symbols. However, a putative face-specific attention resource should be unaffected by symbol CIT irrespective of task demands. Moreover, in Experiment 3 the task was equated between face and symbol CITs, yet no RT repetition priming from distractor faces was received. Thus, this explanation cannot account for the current findings.

The absence of RT priming from face distractors could also be owed to the use of a gender decision task in the prime phase, which is in contrast to Bindemann and co-workers (2007), who employed a nationality decision task. As a result, the processing of stimuli was probably shallower in the present experiments and might not have tapped into face identification. Some support for this idea were the generally faster responses to prime displays when compared to performance in Bindemann and co-workers (2007). One has to consider, though, that in the present study some amount of priming in RTs emerged for target CITs *despite* the probably shallower processing during the prime phase. Additionally, ERP repetition effects were observed from the distractors when presented alongside symbol targets, suggesting that repetition priming does not rely so much on semantic processing at prime presentation. This is in line with the demonstration by Ellis and Young (1990) of repetition priming irrespective of whether the prime task required semantic processing (occupation judgements) or gender judgements.

Finally, the distance between flanking face distractors and target CITs might account for the present results. Face distractors in our experiments had been presented at a visual angle (VA) of 1.8° laterally from the CITs, compared with 1.0° VA in Bindemann (2007). This potentially critical aspect is discussed in greater detail below in a separate section (6.3).

In sum, the consistent behavioural evidence for distractor processing as seen in congruency effects in strand 1 despite the absence of long-term repetition effect in RTs suggested that some degree of distractor face processing had occurred in the current paradigm, but that the consequences of such processing might have been very transient, at least in terms of its influence on participants' behavioural responses. The observation of ERP repetition effects from face distractors when flanking symbol CITs suggested that distractors can actually influence subsequent processing.

Although participants were encouraged to attend to targets only, experiments in strand 1 did not manipulate attentional demands. It thus cannot be ruled out that the gender decision task in Strand 1 did not exhaust *general* attention resources. As a result, one cannot be sure that the results of preserved, or residual, distractor processing for symbol target CITs were due to face-specific attention resources or simply because symbols never exhausted the general attention resource. Face CITs, in contrast, could have always exhausted the general attention resource (instead of loading a putative face-specific attention resource with a capacity limit of one), thus eliminating distractor processing.

In research stand 2, as described below, a new experimental paradigm is introduced, designed to account for possible shortcomings in strand 1, and to extend the promising results in terms of neural correlates of a face-specific attention resource obtained in the present series of experiments by additionally manipulating attentional demands.

6.2. Immediate repetition effects from unattended faces

Considering the numerical increase of distractor processing with decreased time lag between prime and probe presentation seen in interference effects in strand 1, the experiments in strand 2 minimised this lag by applying an immediate repetition paradigm (cf. Schweinberger et al., 2004). ERPs to immediate face distractor repetitions were recorded while attention to unrelated target CITs was manipulated according to the Perceptual Load Theory (Lavie, 1995). As detailed above, no behavioural index of repetition priming was assessed. CITs were letter strings (Experiment 4), unfamiliar faces vs. unfamiliar buildings (Experiment 5), or familiar vs. unfamiliar faces (Experiment 6).

The scope of Experiment 4 (Neumann & Schweinberger, 2008) was to investigate neural correlates of repetition priming by distractor faces presented under conditions of low vs. high perceptual load. Perceptual Load Theory would predict inevitable processing of distractors when spare attentional resources are available after processing of task-relevant material. Accordingly, distractor processing is thought to be absent when the attention resource required for distractor processing is occupied by task-relevant material. In contrast to this assumption, Lavie et al. (2003) found intact interference from distractor faces on central names, and Jenkins et al. (2003) reported spared priming in RTs for distractor faces presented under high load.

Considering the possible role of eccentricity on distractor processing (see also below, p.96), an experimental setup was adapted from Jenkins et al. (2003), in which target letter strings were presented superimposed on the centre of a distractor face stimulus.

Experiment 5 (Neumann & Schweinberger, submitted) targeted the issue of a face specific attention resource by investigating the putative capacity limit using an adapted version of the immediate repetition paradigm used in Experiment 4. In contrast to Experiment 4, CITs were either small face or building CITs, superimposed on the nose region of the face distractor. Perceptual load was manipulated by varying task demands (Lavie, 1995). Assuming a putative capacity limit for face processing of one face at a time, face distractor processing should be *eliminated* in face CIT conditions, i.e., when a second face is simultaneously presented in the prime display. By contrast, face distractor processing should be *preserved* in building CIT conditions, i.e., when only one face (the distractor) is displayed, thus allowing for repetition effects in ERPs to occur. In line with the results from Strand 1, perceptual load should not affect repetition effects, i.e. the N250r and the N400 in the present experiments. In sum, preserved repetition effects from building CITs and abolished repetition effects from face CITs were expected under both high and low load conditions.

Following up on Experiment 5, Experiment 6 directly compared repetition effects from famous face distractors when target CITs were unfamiliar vs. familiar faces.

Contrary to the predictions of the Perceptual Load Theory, identical N250r repetition effects from face distractors were observed in Experiment 4 at occipito-temporal sites, irrespective of whether primes were presented under high or under low perceptual load. Although in conflict with the Perceptual Load Theorie, this pattern is in line with results of Jenkins (2003), who also found identical priming in RTs for faces under high and low perceptual load. Moreover, a later ERP deflection at central electrodes between 400 and 600 ms, likely reflecting an N400 modulation, revealed repetition effects which were again unaffected by perceptual load, suggesting that face distractor processing under high load conditions can access higher processing levels, which have typically been associated to activations of semantic information (e.g., Pickering & Schweinberger, 2003).

As suggested by others (Bindemann et al., 2005; Jenkins et al., 2003), assuming a separate face-specific attention resource could explain the extraordinary role of faces in attention observed not only in Experiment 4, but also reported by studies using a variety of different approaches (i.e., temporal attention, attention capture by faces, repetition priming by “unattended” prime faces). As outlined in the introduction, other researchers had brought forward an alternative explanation: One could assume that face processing is completely automatic in the sense that it can be achieved without attention involvement. However, this explanation would require face processing to be rapid, non-conscious, mandatory, and capacity-free (cf. Palermo & Rhodes, 2007). The results from strand 1 and other recent studies (Bindemann et al., 2005; Bindemann, Jenkins et al., 2007), providing evidence for a capacity limit for face processing of one face at a time, are a considerable challenge to the idea of capacity-free face processing. However, no study directly manipulated attention load, and all studies presented targets and distractors at separate locations. By contrast, in Experiment 5 both target CITs and distractor faces were presented centrally, and attention was manipulated according to the Perceptual Load Theory.

Replicating the key result from Experiment 4, identical N250r repetition effects were found for high and low perceptual load when target CITs were buildings, the condition which was most comparable to the letter string CITs in Experiment 4. By contrast, N250r was reduced for face CIT conditions at single electrode sites, when participants performed age judgements (i.e., high load). Against our initial expectations, a similar reduction of the N250r for face vs. building CITs was not observed for low load conditions: N250r effects were identical irrespective of CIT. It may be suggested that under low load, i.e., during the colour judgement task, no domain specific processing resources were activated. For this task it was not critical to perceive, or even identify, a face. Colour judgments could have been made without analysing shape, or surface texture of the specific CIT to be judged. As a consequence, faces may not have required the specific attention resource and thus, face distractor processing was undistinguishable for face and building CITs.

However, also in contrast the initial hypotheses, residual priming in terms of a small N250r was present even for the high load face CIT condition. One possible reason may have been the combined presentation of familiar faces as distractors and unfamiliar faces as target CITs. Accordingly, attention may have been captured by the potentially more salient, or interesting, famous face distractors. Alternatively, unfamiliar faces may have been processed like objects rather than faces (cf. Megreya & Burton, 2006), and thus may have allowed for residual distractor face processing.

A follow-up Experiment 6 directly investigated this idea by using famous and unfamiliar face CITs, while again ERP repetition effects from famous distractor faces were recorded. In line with the initial prediction, N250r or N400 repetition effects were completely absent for the famous face CIT condition. However, distractor faces combined with unfamiliar face CITs also elicited no substantial and significant N250r in Experiment 6, which is at some variance both with the hypothesis and the results from the analogous condition in Experiment 5. One possible explanation, though clearly post-hoc at present, is related to the randomised presentation of famous and unfamiliar face CITs, which might have caused participants to attempt to identify all target faces, irrespective of whether these were familiar or unfamiliar. This in turn might have caused the overall absence of repetition priming by distractor faces. In general, this finding supports the idea that only one face can be processed at a time. However, the origin of the residual priming from distractor faces when presented in combination with unfamiliar face CITs in Experiment 5 remains unresolved and will have to be addressed in future studies.

As mentioned earlier, one difference between the experiments reported in strand 1 and earlier studies was the spatial distance of a distractor face from a target CIT, i.e., the eccentricity, which is subject to closer examination in the following section.

6.3. The role of eccentricity for distractor processing

The amount of cortex devoted to code one degree of retinal area decreases with eccentricity of a stimulus from the centre of fixation. For example, when target size is held constant, the contrast sensitivity for any spatial frequency is maximum at the fovea and decreasing with eccentricity (Kelly, 1984). Accordingly, low contrast stimuli can only be recognized at the central visual field, encompassing an area of 2 – 4° visual angle (VA) in diameter (Strasburger & Rentschler, 1996).

For tasks involving target and flanker letters, Eriksen & Eriksen (1974) found a significant reduction of response compatibility effects (i.e., more efficient distractor filtering) from 0.06° VA to 0.5° VA. The authors followed, that the more discriminable the differences in spatial location were, the faster (and more efficient) could selection proceed. Eccentricity has even caused effects in one study (Paquet & Craig, 1997) that have been taken as evidence against the Perceptual Load Theory. Specifically, the authors observed selectivity, i.e., no interference, from letter stimuli presented at a distance of 5° VA laterally to a central target letter in a low load task. This finding has been taken as evidence against one central aspect of the Perceptual Load theory, that is, mandatorily perceptual processing takes place unless all capacity is exhausted. I will elaborate on this aspect later in this discussion section. By directly comparing response competition under high vs. low perceptual load for peripheral vs. central distractors, Beck & Lavie (2005) reported greater interference from a distractor when it was presented centrally at fixation compared to when it was presented peripherally, even though peripheral distractors were presented slightly larger than targets to account for differences in acuity between foveal and peripheral vision ("spatial scaling", cf. Kelly, 1984). This suggests that distractors at fixation are specifically hard to ignore, and that they affect behaviour more than peripheral distractors. However, load manipulation was shown to not only yield an effect on peripheral distractors, but also on centrally fixated distractors, suggesting that processing at fixation requires attention to the same extent as processing peripheral targets.

However, the evidence for such a prominent role of eccentricity on distractor processing is not unequivocal. For instance, when natural scenes were presented, participants' ability to detect animals within this scene was remarkably preserved even at extreme eccentricities of up to 70° VA (Thorpe, Gegenfurtner, Fabre-Thorpe, & Bulthoff, 2001). Moreover, a recent study comparing categorisation of natural scenes at central and lateral presentations (3.6° VA) found no behavioural or ERP differences between performances to central or eccentric positions (Fize, Fabre-Thorpe, Richard, Doyon, & Thorpe, 2005). In contrast to the present experiments, those studies displayed only one natural scene at the same time, and, as noted by the authors themselves, the performance of a living/non-living task in the latter study might not have required much attention at all.

In conclusion, these studies seem to suggest that spatial distance between an irrelevant distractor and the relevant target might play a critical role in how the distractor can actually access visual representation. Accordingly, one could argue that the spatial separation of 1.8° VA in the present Experiments 1-3 may have caused insufficient processing to allow for behavioural repetition priming from laterally presented distractors. However, considering the still small spatial separation, and the rather linear decrease of performance with increasing eccentricity found in related studies (i.e., Thorpe et al., 2001), eccentricity alone is unlikely to explain the absence of behavioural repetition priming. Accordingly, interference and ERP repetition effects in the present experiments were found despite using an eccentricity of 1.8° VA. However, more systematic research is needed to make a clearer statement about the potentially subtle effects of distractor eccentricity on their processing. This issue is further complicated by the finding that an attentional “spotlight”, characterising focussed attention, can vary in size as a function of time and task demand (e.g., Eriksen & Yeh, 1985).

In the following section I will summarise and embed the ERP results obtained from the present experiments into the literature on attention and repetition priming for faces.

6.4. ERP modulations by repetition and attention to faces

Previous research has revealed attention modulations on several ERP components (for a review, cf. Luck, Woodman, & Vogel, 2000). As detailed in the introduction section, a number of ERP components have consistently been reported to be affected by stimulus repetitions. Although the main focus of this thesis was on the interaction of both factors (i.e., how are repetition effects modulated by attention vs. inattention to a prime), and thus on the analysis of *probe* displays, the experimental setup also allowed considering the individual ERP modulations by attention only. Thus, in the experiments presented in this thesis, additional analyses were performed for the *prime* presentations. This might be of particular relevance for early components (P1, N170) that have been consistently reported to be sensitive to attention, but scarcely sensitive to repetition manipulations (as detailed below). Accordingly, effects of attention in ERPs to *probe* presentations that are not in interaction with repetition are unlikely to occur, as participants should devote the same amount of attention to all probes. However, attention to a distractor face varied during prime presentations (as a consequence of perceptual load manipulation), and thus attention effects should occur in ERPs to prime displays. As a limitation, the use of composite displays, consisting of simultaneous presentations of one attended target and one distractor makes it difficult to relate ERPs to the attended vs. the unattended stimulus in prime displays. Therefore, no strong a priori prediction with respect to prime ERP modulations by attention can be made at this point.

6.4.1. P100

The sensory-evoked occipital P100 amplitude is typically enhanced when a stimulus was attended spatially (Clark & Hillyard, 1996; Handy & Khoe, 2005; Heinze, Luck, Mangun, & Hillyard, 1990; Luck, Heinze, Mangun, & Hillyard, 1990;

Mangun & Hillyard, 1988) or temporally (Correa, Lupianez, Madrid, & Tudela, 2006), compared to when the same stimulus was unattended. These attention modulations of the P100 are generated in extrastriate cortex, most likely in posterior fusiform gyrus, in proximity of primary visual projection areas (Heinze et al., 1994) and have been suggested to reflect sensory gating mechanisms (Mangun & Hillyard, 1988), responsible for “early precategorical selection” during visual attention (Mangun, 1995). For ERPs elicited by faces, the P100 component has sometimes been shown to be sensitive to attention modulations (e.g., Rossion et al., 1999), whereas in other studies it seemed unaffected (Eimer, 2000b). It has been suggested that the influence of attention on early ERPs as P100 is diminished when complex tasks (i.e., attending ring-shaped regions in space) were involved (Eimer, 1999, 2000a). Instead, attention might influence rather late, post-perceptual mechanisms (but see Correa et al., 2006 when testing temporal attention).

Overall, in none of the experiments presented here, repetition or attention modulated P100 to *probe* faces. This is well in line with previous findings, as the P100 has usually not been found to be sensitive to repetitions (Schweinberger et al., 1995; Schweinberger, Pickering, Burton et al., 2002), and, as reasoned above, there were no differences in attentional demands to probe faces.

Moreover, ERPs to S1 *prime* displays of the present experiments that manipulated attention (i.e., Exeriment 4 through 6) were also largely unaffected by attention, which is in contrast to above mentioned studies that reported a P100 modulation by attention. Only Experiment 4 revealed small ERP modulations by attention in the time segment of the P100. In line with previous findings, amplitudes in left occipito-temporal regions were slightly enhanced for low load conditions vs. high load conditions. Availability of attention beyond processing of letter string CITs may have enhanced P100 responses to composite displays consisting of both letter string targets and face distractors, while this was clearly not the case in experiments 5 and 6, in which composite displays contained buildings or additional faces. Considering the rather small effects in Experiment 4 and the otherwise absent P100 modulations for high vs. low load conditions in Experiments 5 and 6, one could speculate that the small effects observed in Experiment 4 reflected systematic perceptual differences between low and high load conditions (i.e., in the letter strings) rather than attention effects per se. In the terminology of perceptual load theory, capacity in the present prime composite displays presumably has been exhausted in both high and low load conditions: either by the target (face, symbol, or house) or by the additional distractor (face), which were presented at the same spatial location. By contrast, the decrease in P100 amplitude by inattention in previous studies was caused by the setup, which required participants to attend to one spatial location, while the respective stimulus was presented at a different location (e.g., Clark & Hillyard, 1996; Handy & Khoe, 2005).

6.4.2. N170

It is discussed controversially whether i) the N170 is sensitive to attention modulations (Eimer, 2000c; Holmes, Vuilleumier, & Eimer, 2003) or not (Cauquil, Edmonds, & Taylor, 2000), and ii) whether it is sensitive to face repetitions (Itier, Latinus, & Taylor, 2006; Itier & Taylor, 2004b; Jemel et al., 2005) or not (Eimer, 2000c; Engst et al., 2006; Schweinberger et al., 1995). Attentional modulations of the N170 were present for faces, but not for chairs in one study (Eimer, 2000b), and they were accordingly interpreted as modulations of processing within face-specific brain regions.

The present experiments yielded inconclusive evidence for an influence of attention on the N170. In Experiment 5 though, larger N170s in response to low load *prime* trials than in high load prime trials were received, which is in line with previously reported N170 attention modulations (Eimer, 2000b).

A shortcoming of some previous studies might relate to the attention modulation, as exemplified on one study by Cauquil (2000). These authors randomly presented a stream of images consisting of upright faces (eye gaze straight, averted, or eyes closed), inverted faces, phase-scrambled faces, eyes only, lips only, and flowers. Participants responded by button press whenever they saw either eyes only or faces with eyes closed (“target condition”). The main result was a null-effect, corresponding to the N170 to upright faces being unaffected by attention. The authors interpreted this result as supporting the assumption that early face processing, as indexed by the N170, can occur independent from selective attention. However, from the Perceptual Load Theory’s perspective, this study clearly lacks a control for selective attention. Assuming that instructing participants to selectively attend to certain stimulus categories will cause non-target stimuli to remain unattended is insufficient according to the Perceptual Load Theory. Instead, processing is inevitable when processing resources are available. Hence, the null-effect in this study may be explained by a potentially ineffective attention modulation.

In contrast, the approach in the present experiments avoided this potential flaw: Attention was measured according to its influence on face distractor processing, reflected in later repetition effects. This approach was advantageous, as selective attention to prime faces was manipulated carefully according to the Perceptual Load Theory, and later repetition effects were uncontaminated by either motor responses and influence from the presence of a second item in the display. However, it should again be noted that all Experiments presented here focussed on attention influences on *repetition effects*, and considering the inconclusive results related to N170 modulations by either factor, no a priori hypothesis concerning the N170 was formulated. Thus, further research is needed to examine the influence of attention on the N170, which more carefully accounts for an effective attention manipulation according to the Perceptual Load Theory.

Using different approaches, quite promising results were reported: Heisz et al. (2006) found N170 habituation (progressive decrease) with repeated presentations of same faces when these were presented at unattended spatial locations, and interpreted this finding as a relatively pure observation of automatic early face processing. This observation suggested that the special ability of faces in processing under limited attention could occur at the level of structural encoding, as reflected by N170 modulations. Moreover, N170 to laterally presented faces was reduced when participants concurrently viewed centrally presented objects of expertise (“Greebles”), but not, when they viewed untrained objects (Rossion et al., 2004), supporting separate attention resources for faces (plus objects of expertise) and (untrained) objects.

In sum, structural encoding of faces as indexed by N170 occurred irrespective of whether or not attention was available in prime displays (i.e., low vs. high load) in the present experiments, as no consistent N170 load modulation to prime displays was observed. Although in contrast to some previous studies (Eimer, 2000b; Holmes et al., 2003), this finding is broadly in line with other research (Heisz et al., 2006), and matches the ERP repetition results in terms of N250r effects described below.

6.4.3. N250r

While some of the above-mentioned evidence for the N170 can be interpreted as supporting face-specific attention modulations (Eimer, 2000c), face-selectivity of the

N170 is matter of ongoing debate (see, e.g., Rossion & Jacques, 2008; Thierry et al., 2007). For example, the N170 in response to car fronts is indistinguishable from the N170 elicited by faces (Schweinberger et al., 2004). In contrast, the N250r has consistently been found to be enhanced for faces than for other objects, and could thus provide more compelling evidence in favour of face-specific attention modulations.

Previous to the present experiments, the influence of attention on the face-specific N250r has not been systematically investigated. As detailed above, however, related studies (Martens et al., 2006; Trenner et al., 2004) have suggested an influence of either task-relevance or attention on N250r amplitudes.

The results from the Experiments 4-6 indicated that attention modulation to primes had no significant influence on the N250r to probes: N250r was elicited irrespective of whether the prime face was presented under high or low load to an unrelated letter string. Importantly, the N250r was significantly reduced or even absent when an additional face had to be attended during prime presentation. Assuming that N250r reflects a stimulus-triggered access to stored facial representations (Bindemann et al., 2008), it seems plausible from the present research that access to stored facial representations occurs independent from a general attention resource. Moreover, according to the present findings, stimulus-triggered *simultaneous* access to more than one facial representation, or FRU (according to the IAC model; Burton et al., 1990) is difficult or even impossible to accomplish. Until now, the IAC model does not make a clear prediction about whether it is possible or not to simultaneously access two FRUs. Correspondingly, the current research adds this novel detail to the IAC model of face recognition.

6.4.4. N400

The experiments in strand 2 revealed that faces presented under conditions of highly restricted general attention resources elicited N400 repetition modulations to a similar extent as faces presented under less restricted availability of attention (i.e., low load). This is in contrast to Eimer (2000c), who reported N400 familiarity modulations for attended, but not for unattended faces. Similar to other studies, however (Martens et al., 2006; Trenner et al., 2004), in that study task-relevance and attention were confounded, thus restricting any conclusions about the specific contribution of attention.

Overall, N400 results in strand 2 paralleled those observed for the N250r, indicating that the suggested independence of face processing from a *general* attention resource might even exceed processing stages associated with activation at the FRU level, and instead can occur at semantic processing levels (PINs/SIUs), as long as only one face is being processed at a time. With adding another face to the display, however, repetition modulations between 400 and 600 ms were reduced to insignificance in Experiment 3. Moreover, these repetition modulations in Experiment 3 were observed in the absence of behavioural repetition priming, i.e., faster or more accurate responses. N400 repetition modulations in absence of behavioural priming have been described previously (Heil & Rolke, 2004), and could possibly be explained within the IAC model by an activation gain on the PIN level, which may have failed to reach a threshold activation level needed to support behavioural priming.

It has recently been shown that subliminal prime word presentations (masked priming) can elicit N400 modulations almost to the same extent as overt presentation (Holcomb, Reder, Misra, & Grainger, 2005; Kiefer, 2002; but see Brown & Hagoort, 1993), suggesting that N400 modulations can occur from automatic spreading of activation, and not solely from strategic semantic processes (Kiefer, 2002). However, attention to the masked prime was a prerequisite for N400 effects to occur under these conditions (Kiefer & Brendel, 2006).

In the previous sections, repetition priming and interference from faces under high load has been discussed as supporting a capacity-limited, face-specific attention resource. The following section outlines alternative perspectives on the remarkable degree of processing of presumably unattended faces. In this context, differential contributions of attention and awareness in face processing are discussed, as priming by unconsciously perceived faces has sometimes been interpreted as automatic face processing.

6.5. Alternative perspectives on processing ignored faces

6.5.1. Automaticity account

In the introduction section, I outlined some evidence that has been interpreted as supporting automatic face processing by the authors. However, these results, showing processing of *unattended* faces, could alternatively be interpreted by assuming the existence of a face-specific attention resource. Additional evidence for the automaticity claim came from recent studies that tested repetition priming by *uncon-*

sciously perceived faces. These studies typically used a masking procedure, i.e., either displayed a face briefly preceded and succeeded by noise or pattern masks ("sandwich masking"), or presented the mask either only before or after the shortly presented face image (forward and backward masking, respectively). Sandwich masking renders the face "invisible", that is, not consciously perceived, and non-reportable (for a review, cf. Kouider & Dehaene, 2007).

Brain regions in the right fusiform gyrus can be activated by unconsciously perceived masked faces, suggesting that initial face detection, but not object detection might be an automatic process (Morris, Pelphrey, & McCarthy, 2007). Even categorical priming can be obtained under conditions of highly restricted awareness (Stone & Valentine, 2007). The authors followed that semantic information, i.e. the occupation, can be extracted from masked prime faces presented for 17 ms only. However, unconscious processing in masked priming has been described to be modulated by temporal attention to the prime (Kiefer & Brendel, 2006). Accordingly, Trenner and co-workers (2004) failed to find masked priming from faces when the onset of the prime was not predictable, and was thus supposedly unattended. In contrast, and assuring temporal predictability, Martens and co-workers (2006) reported weak masked priming effects in early ERPs (100-150 ms and N170), while behavioural priming remained absent. Behavioural masked priming, and stronger ERP evidence for priming by non-consciously perceived faces has recently been provided (Henson, Mouchlianitis, Matthews, & Kouider, 2008). The authors reported a reliable early priming effect similar to Martens et al. (2006), occurring even across different views of a face and irrespective of whether famous or unfamiliar faces were presented. In addition, a later N400 priming effect was found from masked famous faces, presumably reflecting semantic processing analogous to the behavioural evidence reported by Stone & Valentine (2007).

More generally, the above-mentioned masked priming by faces was interpreted as reflecting some type of automatic face processing, which might exceed simple detection of faces, and may also include certain aspects of identity and semantic processing. At first sight, this claim might be related to the idea of automatic face processing in the absence of attention (Jenkins et al., 2002; Lavie et al., 2003). However, it has been shown that attention and awareness, though often tightly coupled, can be dissociated (Kanai, Tsuchiya, & Verstraten, 2006; Kouider & Dehaene, 2007). Specifically, Dehaene et al. (2006) proposed a taxonomy of four different processing types according to whether bottom-up stimulus strength is weak (i.e., in brief and masked presentation) or strong (conscious perception) and whether top-down attention is absent or present. Hence, masked priming by attended faces has resulted in "subliminal attended" processing (weak / attended), whereas repetition priming by (supposedly) unattended faces, as tested in the current Experiments, has presumably resulted in "preconscious" processing (strong / unattended).

This taxonomy not only assumes different mechanisms for the processing of unattended vs. unconsciously perceived faces, but also points out that evidence from masked priming studies can not be interpreted in terms of automatic face processing, which would require independence from attention (Schneider & Shiffrin, 1977; see also Kouider & Dehaene, 2007). Supporting the assumption of a distinct mechanism underlying masked priming, a recent functional imaging study contrasted data from masked direct repetition priming with long-term priming from consciously perceived famous faces (Kouider, Eger, Dolan, & Henson, 2009). Critically, the authors found a general pattern of masked (subliminal) priming from familiar and unfamiliar faces, regardless of whether same or different images were used as probes. By contrast, long-term priming was observed only from familiar faces, but not from unfamiliar faces. Finally, while masked priming was confined to occipito-temporal regions, overt long-term priming was associated with repetition modulations in additional ventral prefrontal regions. Hence, the authors assumed different underlying neural mechanisms for subliminal and overt long-term priming, which may explain the sensitivity to familiarity observed selectively for long-term priming.

In sum, studies testing masked priming from subliminally presented faces seem to suggest some kind of automaticity in face perception. Even with extremely brief presentation durations, both behavioural and neural evidence for repetition effects were found. However, these findings do not support an "automaticity" account of face processing in the absence of attention. Rather, temporal attention to a prime seems to be a *prerequisite* for repetition effect to emerge (Martens et al., 2006; Shelley-Tremblay & Mack, 1999). Moreover, the existence of a potential capacity limit in activations of face sensitive regions by masked subliminal faces – another critical property of automaticity (Palermo & Rhodes, 2007; Schneider & Shiffrin, 1977) – has not yet been tested. The results obtained from the present experiments and earlier studies (Bindemann et al., 2005; Bindemann, Jenkins et al., 2007) consistently show that face processing is capacity-limited, and strongly argue against an automaticity account. Instead, they favour a face-specific attention resource, which is in itself capacity-limited to the processing of only one face at a time.

6.5.2. General resource account

Finally, a third alternative approach proposes that faces are not special, and their processing is carried out via the same resources that are being accessed by other classes of stimuli (Jackson & Raymond, 2006). In line with this view, Henson & Mouchlianitis (2007) found reliable repetition suppression from faces and houses only when both first and second presentations were attended. The authors argued that perceptual load in other studies (Bentley et al., 2003; Vuilleumier, Schwartz, Duhoux, Dolan, & Driver, 2005) might not have been sufficiently high to eliminate distractor processing. Although this explanation may be applicable, it is not entirely satisfying: a null effect of load (as in Experiment 4) could always be interpreted with ineffective load manipulation, which did not sufficiently tap general attention resources (see Snow & Mattingley, 2008, for a similar reasoning).

Actually, contradicting their argumentation, Henson & Mouchlianitis (2007) applied a task in which perceptual load was reasonably *low*: Buildings and faces were presented easily recognisable and for a sufficient duration at a predefined position in the spatial field, and were temporally predictable. Moreover, the task was not demanding, as participants were required to make simple face vs. house distinctions. Therefore, perceptual load alone might not be sufficient to explain why repetition suppression was modulated by attention in this study (and in Eger et al., 2004), but not in others that used a similar setup (Bentley et al., 2003; Vuilleumier et al., 2005).

Taking a closer look at the data of Henson & Mouchlianitis (2007), there actually *was* evidence for distractor processing, even though this did not lead to reliable repetition suppression. Specifically, response times were faster, when the contralaterally presented stimulus was of the same category (i.e., when a face was attended and a face distractor was displayed). Similarly, neural responses were stronger in the respective stimulus-sensitive region under these conditions, suggesting that distractor processing occurred. Moreover, when faces were ignored at first presentation (the “ignored-attended” condition), neural activation in the right FFA showed repetition suppression that was numerically identical to the “attended-attended” (i.e., faces were attended at both first and second presentations) condition, but did not quite reach significance, maybe due to larger variance. In fact, repetition suppression even for the “attended-attended” conditions was numerically small for faces, suggesting that other factors than attention (or perceptual load) may have had an influence on repetition suppression effects. One potential factor could have been the spatial separation of distractor and target stimulus.

In line with this latter point, a study that presented target and distractor without spatial separation (superimposed objects) reported behavioural and neural repetition-related modulations by distractors (Vuilleumier et al., 2005). While explicit recognition for ignored stimuli was completely absent, implicit recognition in terms of priming by both attended and ignored stimuli was found. Thus, the absence of reliable repetition suppression by ignored faces in Henson & Mouchlianitis (2007) does not seem to reflect a complete *absence* of distractor processing. Rather, other factors such as spatial separation may have *reduced* processing in that study.

Although from the present results the “general resource” account cannot be entirely ruled out, some findings are difficult to reconcile with this view. Assuming that faces draw on general attention resources to a larger extent that other objects would implicate prolonged responses to faces than to other objects. This was not observed in the present experiments. In contrast, Experiment 1 and 2 showed the exact opposite pattern with longer response times for symbols than for faces.

In conclusion, results from the present experiments argue for a face-specific attention resource rather than a general resource account. However, the general resource account cannot be completely ruled out from the present results, but so far, no compelling argument in favour of this view has been made either. Specifically, perceptual load alone is unlikely to account for the inconsistent evidence, as outlined above. Thus, future research is needed to elucidate these conflicting views.

6.6. Faces in the Perceptual Load Theory

In line with previous studies (Jenkins et al., 2002; Lavie et al., 2003), the current experiments suggested that faces may be an exception to the strong version of the Perceptual Load Theory (which has been acknowledged by the author, cf. Lavie, 2005). One critical question may be which property of a face causes it to be processed despite being task-irrelevant, and even when the unrelated task is highly demanding.

6.6.1. Familiarity

The conclusions regarding a face-specific, capacity-limited attention resource, drawn from the experiments reported here, are limited to the extent that *celebrities'* faces were tested throughout. It has been argued that only familiar faces require little general attention (Engst et al., 2006), and that familiarity, and not "faceness" per se could account for repetition priming by unattended faces, as seen in the current experiments. Related research pointed out that self-face recognition, a condition of high familiarity with a stimulus, is not influenced by attention (Sui, Zhu, & Han, 2006). Therefore, it appears highly relevant to replicate the current findings using unfamiliar faces. However, face repetition priming is highly sensitive to familiarity. Repetition priming is typically more pronounced for familiar (famous) faces, and reduced or even absent for unfamiliar faces (Henson, Shallice, & Dolan, 2000; but see Goshen-Gottstein & Ganel, 2000). Similarly, N250r repetition effects were found to be more pronounced for familiar than for unfamiliar face repetitions (Begleiter et al., 1995; Herzmann et al., 2004; Pfütze et al., 2002). Hence, considering that face priming would be measured from unfamiliar *distractor* faces, such an approach remains questionable. Still, contrasting personally familiar faces (highly familiar) with celebrities' faces (somewhat familiar) might help to resolve the influence of familiarity in future research.

6.6.2. Salience

Alternatively, but closely related to the familiarity hypothesis, the salience of faces could account for the present results (cf. Landau & Bentin, 2008). Based on findings suggesting that distractor processing may not be mandatory even under low load (Paquet & Craig, 1997), Eltiti et al. (2005) formulated a Salience hypothesis in competition to the Perceptual Load Theory (Lavie, 1995). The authors proposed that rather than perceptual load per se, *salience* of a distractor determines selective processing. Thus, salience of an object should cause greater ease in processing despite being task-irrelevant and presented under restricted attention conditions. One could hypothesise that faces are genuinely more salient stimuli when shown in competition with most (or even all) other stimulus categories, possibly due to their great social significance (e.g., Kanwisher & Moscovitch, 2000). Given that distractor faces in the current experiment *were* always more salient than task-relevant targets (i.e., letter strings, or buildings), this approach might in principle explain the current findings in strand 2.

Related evidence in favour of a salience account derived from patients with spatial neglect after brain lesions. Spatial neglect is characterised by a loss of awareness for stimuli presented at the contralesional side, while visual acuity in both visual fields is intact. Moreover, the patients display a pathological attention bias that favours stimuli presented at the ipsilesional side, resulting in contralesionally presented stimuli to be partially or completely ignored (Heilman & Valenstein, 1979). This attention bias towards the ipsilesional side has been explained by damage to brain regions responsible for the encoding of input salience, resulting in unselective prioritisation of ipsilesional information (Pouget & Driver, 2000). It has been followed that in patients with unilateral neglect the salient ipsilesional information, even when completely irrelevant, should be relatively resistant to filtering (Snow & Mattingley, 2008). Accordingly, the authors conducted a study in which they manipulated perceptual load to a central task and measured interference (that is, slower responses when target-flanker pairings were incompatible with respect to response category, or faster responses, when they were compatible, relative to a neutral flanker condition) from congruent vs. incongruent irrelevant flankers presented ipsi- or contralesionally. Moreover, the authors tested processing of the "extinguished" contralesional flanker. Replicating the attention bias for neglect patients, Snow & Mattingley (2008) reported strong congruency effects from ipsilesionally presented flankers in the patient group. Critically, no influence of Load on the magnitude or pattern of the congruency effects was observed, suggesting that this attention bias cannot be overcome by attentionally demanding unrelated tasks. However, contralesional information also caused some interference irrespective of perceptual load in two patients. Similarly, Vuilleumier and co-workers (2002) reported intact priming from objects presented to the extinguished side, while explicit memory in a forced-choice old-new decision was absent. However, this priming effect for extinguished items was graded, in that effects were smaller when compared to priming from stimuli presented at the "intact" side. Taken together, these studies suggest that salient stimuli (e.g., ipsilesional stimuli for neglect patients) may have a competitive advantage for selection over those that are not as salient (e.g., contralesional stimuli). Accordingly, considerable implicit processing of salient stimuli can take place even under conditions of high load (Snow & Mattingley, 2008), presentation to the extinguished side, and even when explicit recognition is completely absent (Vuilleumier et al., 2002).

6.6.3. Revising the Perceptual Load Theory

As outlined above, the Perceptual Load Theory, although highly applicable for most conditions, cannot account for some selective findings. In the present experiments and in earlier studies (Jenkins et al., 2003; Lavie et al., 2003), famous distractor faces were processed irrespective of high perceptual load in an unrelated task involving letters (e.g., Experiment 4), or buildings (Experiment 5). The respective contributions of "faceness" per se, familiarity, and salience cannot be derived from the present experiments and may require future research.

However, both the perceptual load and the salience account consider distractor processing in an all-or-none manner. Distractors are thought to be processed either fully (under low load, or if they are salient), or not at all (under high load, or if they are not salient). These theories made no predictions that could account for graded processing of distractors (i.e., Experiment 5; Vuilleumier et al., 2005).

Alternatively, one could also think of partial processing of certain *features* of distractors (Chen, 2005; Chen & Cave, 2006). For example, one could speculate that distractor processing is more pronounced when distractors are salient, and that those aspects that are *most* salient at a specific time may be encoded preferably. Encoding of other face properties may be reduced or absent under inattention or high load conditions. Relevant evidence for this idea derived from one recent study (Haberman & Whitney, 2007), which reported that participants were able to extract the emotional content of four simultaneously presented faces, while identity information from the same faces was presumably not encoded (as participants performed at chance level during a subsequent recognition task). Similarly, gaze direction could not be perceived from unattended distractor faces in one recent study (Burton, Bindemann, Langton, Schweinberger, & Jenkins, 2009), while other visual information (i.e., head contour) was processed. The idea of partial distractor processing might help to understand why sometimes neural evidence for repetition effects were observed in the absence of behavioural effects. Accordingly, properties of a distractor face that might facilitate responses on a later presentation are not necessarily those that are salient, and thus the facilitation fails to appear. For example, age information in a face might be more salient than gender information and thus is extracted despite being task-irrelevant, while gender information is extracted only when task-relevant (Wiese et al., 2008). However, such a view would probably challenge the assumption of configural, or "holistic" face processing (Tanaka & Farah, 1993).

Another aspect that is not yet addressed in the Perceptual Load Theory refers to inter- and intraindividual variability in perceptual capacity. It seems highly implausible that each individual possesses identical attentional capacity, e.g. for detecting letters among distractors. Thus, a high load task could be less demanding for one individual than for another. Moreover, this capacity limit could also vary *within* each single individual, due to several factors (e.g., fatigue, stress, motivation, etc.). Accordingly, in the current experiments, some participant's performances were exceptionally good when detecting target letters among different distractor letters, while others performed just above chance level. Studies employing perceptual load manipulations almost never account for such differences (but see Handy, Soltani, & Mangun, 2001 for an adaptive testing account).

In summary, although offering an eminent tool and theoretical background to systematically control for attention, the strict version of the Perceptual Load Theory might require modifications to account for some of the present results. Critically, face distractors, or, more generally, specifically salient distractors, may display an exception to the Perceptual Load Theory. Finally, an implementation of inter-, and intraindividual differences into the Perceptual Load Theory might be a fruitful topic for future research.

7. Outlook

In the present thesis, ERPs in terms of N250r- and N400 components were consistently affected by face distractor repetitions. However, at present it is difficult to relate these effects to behavioural repetition priming. In strand 1, no RT priming for unattended items was observed, and in strand 2 participants were not required to respond to probe faces.

Three possible explanations for the special role of faces in attention were discussed in this thesis: (i) the existence of a face-specific attention resource, capacity limited to the processing of one face at a time, (ii) automaticity of face processing, and (iii) a general resource account. In the present series of experiments, electrophysiological evidence supports a capacity limit in face processing, and was thus interpreted in favour of the face-specific attention resource account. In combination with previous behavioural results (Jenkins et al., 2002; Lavie et al., 2003), these findings substantiate the idea that faces may display an exception to the Perceptual Load Theorie (Lavie, 1995), in that they are not processed within a general attention resource. However, faces may not be the only exception. Eltiti et al. (2005) observed interference from salient distractors even under conditions of high perceptual load, a finding that is compatible with evidence presented here for famous faces. Alternatively, familiarity or salience of the faces, instead of “faceness” per se might be the critical factor for distractor processing under high perceptual load (Engst et al., 2006; Jackson & Raymond, 2006). Thus, replication of the studies presented here using unfamiliar faces is required to account for this possible explanation. Moreover, the present findings raise a number of theoretical issues that also might be addressed in future research. Specifically, the “graded” repetition priming, observed in terms of intact neural repetition effects in the absence of behavioural repetition priming observed in Experiment 3 may require additional studies that carefully control for factors such as familiarity and eccentricity. Furthermore, the sensitivity of the early face-sensitive N170 component to attention modulation should be considered in future studies that systematically control for perceptual load. The current findings from ERPs to prime stimuli in Experiment 4 suggested that N170 amplitudes are largely unaffected by load. However, the simultaneous presentation of famous distractor faces and target letter strings made it difficult to relate ERPs to the attended vs. the unattended stimulus. Furthermore, considering a recently described ERP deflection, the N2pc, might validate the current findings. The N2pc relates to a posterior negativity between 180 and 300 ms contralateral to an attended stimulus event, and is thought to reflect covert orientation in spatially selective attentional processing (Eimer & Kiss, 2007; Woodman & Luck, 1999). In a recent study on attention capture by task-irrelevant emotional faces (Eimer & Kiss, 2007), a single fearful face in an array of neutral faces elicited an N2pc despite being task-irrelevant, while a single neutral face in an array of fearful faces did not show this pattern. Accordingly, some aspects of a face, i.e., the emotional expression information, must have been extracted even from large arrays of faces. This might be a potential constraint to the assumption of a capacity limit in face processing, and should be worthwhile to be approached in future research. Finally, the strict version of the Perceptual Load Theory, as detailed above, cannot account for some of the present results, and results from earlier research (Jenkins et al., 2002; Lavie et al., 2003) and might thus require a degree of modification. Future studies may also address the potential influence of distractor salience, and inter- and intraindividual variability within the concept of perceptual load.

8. References

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Summary

This thesis investigated the processing of spatially unattended, that is, “ignored” faces. A matter of considerable debate over the last decades in the field of selective attention is whether ignored information is excluded, or “filtered” from further analysis, or whether it can be partly or even entirely processed. Conflicting evidence regarding the stage of the putative filter process (early vs. late filter account), were recently integrated into a capacity account of selective attention, the “Perceptual Load Theory”. This theory assumes an attention system with limited capacity, in which irrelevant information is mandatorily processed, as long as the processing of relevant information does not exhaust all of the available capacity. Recent studies have suggested that faces might be an exception to this account. There is now considerable evidence for the idea that faces might capture attention to a greater extent than other stimulus classes. Similarly, recent studies demonstrated that task-irrelevant faces, but not task-irrelevant non-faces, may affect processing of task-relevant information under conditions of high perceptual load. Furthermore, task-irrelevant faces were shown to elicit repetition effects (repetition priming) during subsequent stimulus presentations. However, new studies have reported face processing as being capacity limited, in that only one face can be processed at a time. This finding strongly argues against an “automaticity” account of face processing which was recently posited.

Using two lines of research, this thesis investigated long-term and immediate repetition effects from – presumably – unattended faces. The use of event-related brain potentials allowed a more detailed insight into the neural processes underlying the remarkable property of faces to be processed in the near absence of general attention resources. One main aspect of this thesis was to show that face processing is by no means unlimited, i.e. “automatic”. Rather, the experiments presented here provide the first neural evidence for a separate attention module with limited capacity, which is well-suited to, or specific for, the processing of faces.

Zusammenfassung

Diese These untersuchte, ob – und falls ja, wie – räumlich ignorierte Gesichter verarbeitet werden. Eine seit Jahrzehnten andauernde Debatte in der Forschung zu selektiver Aufmerksamkeit betrifft die Frage, ob Informationen, die durch selektive Aufmerksamkeitsprozesse nicht beachtet werden, tatsächlich von der Weiterverarbeitung ausgeschlossen, oder „gefiltert“ werden, oder ob sie teilweise oder vollständig mitverarbeitet werden. Widersprüchliche Befunde der Filtertheorien insbesondere bezüglich des Zeitpunktes eines angenommenen Filterprozesses (frühe vs. späte Selektion) wurden kürzlich in einer Kapazitätstheorie der selektiven Aufmerksamkeit integriert, der sogenannten „Perceptual Load Theorie“. Diese nimmt an, dass innerhalb eines kapazitätslimitierten Systems irrelevante Informationen zwangsläufig verarbeitet werden, sofern die Ressourcen durch die Verarbeitung relevanter Informationen noch nicht erschöpft sind. Jüngere Studien haben zeigen können, dass Gesichter möglicherweise eine Ausnahme von dieser Theorie darstellen können. Tatsächlich gibt es mittlerweile eine Vielzahl an Hinweisen, dass Gesichter stärker als andere Reize Aufmerksamkeit auf sich lenken können. Andere Studien haben zudem zeigen können, dass selbst unter hoher perzeptueller Beanspruchung aufgabenirrelevante Gesichter, nicht aber aufgabenirrelevante „Nicht-Gesichter“, Einfluss auf die Verarbeitung gleichzeitig oder nachfolgend präsentierter aufgabenrelevanter Reize nehmen können. Gegen die Schlussfolgerung, dass Gesichter „automatisch“ verarbeitet werden, sprechen allerdings neue Studien, die zeigten, dass nicht mehr als ein Gesicht gleichzeitig verarbeitet werden kann.

In zwei Experimentlinien untersuchte diese These lang- und kurzzeitige Wiederholungseffekte von vermeintlich unbeachteten Gesichtern. Dabei erlaubten ereigniskorrelierte Hirnpotentiale eine präzisere Analyse der Prozesse, die der außergewöhnlichen Eigenschaft der Gesichter, scheinbar ohne Beanspruchung allgemeiner Aufmerksamkeitsressourcen verarbeitet werden zu können, zugrunde liegen könnten. Ein besonderer Fokus lag auf dem Aspekt, dass die Verarbeitung von Gesichtern dabei keinesfalls unbegrenzt, oder „automatisch“, erfolgt. Vielmehr zeigten die hier präsentierten Ergebnisse erstmals neuronale Korrelaten eines separaten, kapazitätslimitierten, Aufmerksamkeitsmoduls, das besonders geeignet oder sogar spezialisiert für die Verarbeitung von Gesichtern ist.

List of abbreviations

AB	attentional blink
CIT	central item type
EEG	electroencephalogram
ERP	event-related potential
FFA	fusiform face area
fMRI	functional magnetic resonance imaging
FRU	face recognition unit
IAC	interactive activation and competition
PIN	person identity node
PPA	parahippocampal place area
ROI	region of interest
RSVP	rapid serial visual presentation
RT	response time
SIU	semantic information unit
VA	visual angle

Contributions to publications

In line with the APA criteria for first authorship, I was the principal contributor to all aspects of experiment conception, data analyses, and manuscript preparation of all publications included in this thesis.

Prof. Stefan R. Schweinberger contributed to the conception of experiments, and manuscript preparation of all publications included in this thesis.

Dr. Holger Wiese made essential contributions to EEG routines and analysis, and discussion of the manuscript.

Prof. A. Mike Burton contributed to the setup of the experimental design, and discussion of the manuscript.

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Ehrenwörtliche Erklärung

Ich erkläre, dass mir die geltende Promotionsordnung der Fakultät für Sozial- und Verhaltenswissenschaften der Friedrich-Schiller-Universität Jena bekannt ist.

Ferner erkläre ich, dass ich die vorliegende Dissertation selbstständig ohne die Hilfe Dritter angefertigt habe, sowie alle benutzten Quellen und Hilfsmittel in der Arbeit angegeben habe. Insbesondere habe ich keine Hilfe eines Promotionsberaters in Anspruch genommen.

Bei der Auswahl und Auswertung des Materials sowie der Herstellung des Manuskriptes hat mich Prof. Stefan R. Schweinberger unentgeltlich unterstützt. Darüber hinaus hat kein Dritter unmittelbar oder mittelbar geldwerte Leistungen von mir für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

Ich erkläre weiterhin, dass ich diese Dissertation noch nicht als Prüfungsarbeit für eine staatliche oder andere wissenschaftliche Prüfung, oder eine gleiche, eine in wesentlichen Teilen ähnliche oder eine andere Abhandlung bei einer anderen Hochschule bzw. anderen Fakultät als Dissertation eingereicht habe.

Ich versichere, nach bestem Wissen die reine Wahrheit gesagt und nichts verschwiegen zu haben.

Jena, 22. Januar 2009 ______________________________